MAGNETIC COMPENSATION AND FEEDBACK IN A SERIES CONNECTED MAGNETIC AMPLIFIER WITH UNMATCHED CORES

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Submitted in partial fulfillment of
the requirements for the degree of

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IN
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ABSTRACT

At present, it is impossible to produce magnetic cores having identical magnetic properties. "Matched" cores may be obtained by testing several cores produced by an identical process and selecting the cores having the most nearly identical magnetic properties. Since perfectly matched cores are seldom, if ever, obtained by this procedure, the criteria for matched cores are determined by specification.

This is a report of an investigation of the possibility of obtaining matched core performance from unmatched cores by using a dynamic balancing circuit employing magnetic feedback.

The writer wishes to express his appreciation for the assistance and encouragement given him by Professor Charles H. Rothauge of the U. S. Naval Postgraduate School in this investigation.

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LIST OF ILLUSTRATIONS

GLOSSARY

Terms:

Compensated - Core f is in the circuit, coupled to cores 1 and 2.

Identical cores - Physically identical, but unmatched cores.

Matched cores - Magnetically identical cores.

Series configuration - Shunt capacitor across control windings is not in the circuit.

Shunt configuration - Shunt capacitor is across control windings.

Uncompensated - Core f is not in the circuit.

Symbols:

C - Capacitor

Circuit designator - (DPS - 12.5 series) The first two letters indicate core material of cores 1 and 2; the third letter, if present, indicates core material of core f, if in the circuit; the numbers indicate the percent feedback, if any; the word indicates the configuration.

D - Deltamax.

e - Instantaneous or alternating voltage.

E - Average or direct current voltage.

f - Compensating and feedback core.

i - Instantaneous or pulsating current.

I - Average or direct current.

k - Represents the voltage difference across the core windings of core 1 and core 2 in a particular circuit.

L - Inductance.

N - Number of turns.

P - 4-79 Mo-Permalloy.

q - Charge; integral of current with respect to time.

R, r - Resistance.

S - Supermalloy.

t - Time.

Z - Impedance.

ϕ - Flux.

Subscript notation:

a - Alternating.

c - Control circuit.

L - Load circuit.

1 - Associated with core 1.

2 - Associated with core 2.

f - Associated with core f.

' - First derivative with respect to time.

1. Introduction.

The theory of operation of series connected magnetic amplifiers is based on the magnetic cores having identical magnetic properties. Such cores are, at present, practically impossible to obtain. Fortunately, for most applications cores can be obtained whose magnetic properties are sufficiently identical to cause the effect of their mismatch to be negligible. Unfortunately, the cost of these magnetically identical (matched) cores is several times the cost of physically identical (unmatched) cores.

Matched and unmatched cores are made by the same process. The additional cost for matched cores is made necessary by the additional testing which must be done to find cores of nearly identical magnetic properties, a process of inspection and selection.

If, by using simple, inexpensive circuitry, a method could be found to cause unmatched cores to give the same performance as matched cores, the cost of magnetic amplifiers might be reduced and their performance improved. This is a report of the investigation of such a circuit. The objectives of this investigation were:

(a) To obtain the performance of matched cores using unmatched cores in a series connected magnetic amplifier.

(b) To study the effect of magnetic feedback and compare the results with those obtained by conventional feedback methods.

A bibliography is not included in this report. An excellent

background in magnetic amplifier circuits is contained in "Magnetic Amplifiers," by George M. Ettinger, published by Methuen and Company, Ltd., London, and distributed by John Wiley and Sons, Inc., New York. This publication contains a very complete bibliography and reading list.

2. Theory of Operation.

Consider the circuit of Fig. 1, with core F omitted and N_1, N_2, and $N_f = 0$. The sum of voltages around the load circuit is

$$E_a - N_{L_1}\phi_1' - N_{L_2}\phi_2' - i_L R_L = 0 \qquad (1)$$

$$e_{L1} = -N_{L1}\phi_1' = -L_1 i_L' \qquad (2)$$

$$e_{L2} = -N_{L2}\phi_2' = -L_2 i_L' \qquad (3)$$

Since the inductance, L, is a variable non-linear function of the magnetic properties of the core, it can be seen from equations (2) and (3) that $N_{L1}\phi_1'$ and $N_{L2}\phi_2'$ are dependent on the magnetic properties of the respective cores with which they are associated, and can only be equal when the magnetic properties of each core are identical, or when $i_L' = 0$. Since cores having identical properties are not readily obtainable, the voltage across N_{L1} will differ from the voltage across N_{L2} by an amount proportional to the difference in magnetic properties of the cores.

Consider core f in the circuit, coupled to core 1 and core 2 by coils N_1 and N_2 respectively. Neglecting the small resistance of the coils N_1 and N_2, and summing voltages around the coupling or compensating circuits yield

$$N_1\phi_1' - N_1\phi_f' = 0 \qquad (4)$$

$$N_2\phi'_2 - N_2\phi'_f = 0 \tag{5}$$

From equations (4) and (5), it is seen that

$$\phi'_1 = \phi'_2 = \phi'_f \tag{6}$$

When N_{L1} equals N_{L2}, equations (1) and (6) yield

$$E_a - 2N_L\phi'_1 - i_LR_L = 0 \tag{7}$$

Connect coil N_f in the load circuit coupled to core f. The sum of voltages around the load circuit is now

$$E_a - (2N_L - N_f)\phi'_1 - i_LR_L = 0 \tag{8}$$

If core f is removed from the circuit, and the capacitor connected across the terminals of the ammeter in the control circuit in series with coils N_{c1} and N_{c2}, two possible conditions exist in the control circuit.

$$N_{c1}\phi'_1 - N_{c2}\phi'_2 + i_{ca}Z_c = 0 \tag{9}$$

One possible condition exists when $i_{ca} = 0$.

$$N_{c1}\phi'_1 = N_{c2}\phi'_2 \tag{10}$$

Since there is no alternating current, the voltage across N_{c1} and N_{c2} is zero, and

$$N_{c1}\phi'_1 = N_{c2}\phi'_2 = 0 \tag{11}$$

The other condition exists when i_{ca} is not equal to zero.

$$N_{c1}\phi'_1 - N_{c2}\phi'_2 = -i_{ca}Z_c \neq 0 \tag{12}$$

$$N_{c1}\phi'_1 \neq N_{c2}\phi'_2 \tag{13}$$

Equation (13) shows that when N_{c1} equals N_{c2}, the magnetic properties of core 1 and core 2 are not identical when an alternating current flows through an impedance in series with the control windings.

Consider the capacitor in the load circuit to be placed in shunt with the control windings, and to be sufficiently large to provide an effective a.c. short circuit. Summing voltages around the a.c. path in the control circuit yields

$$N_{c1}\phi_1' - N_{c2}\phi_2' = 0 \qquad (14)$$

and when N_{c1} equals N_{c2}

$$\phi_1' = \phi_2' \qquad (15)$$

Thus an effective a.c. short circuit shunt causes core 1 and core 2 to exhibit identical properties.

When core f is coupled in the circuit, the rate of change of flux in all cores is equal from equation (6). Hence from equation (9), an alternating current cannot flow in the control circuit when the shunt capacitor is omitted and an impedance is in series with the control windings.

3. Test Procedure.

Control characteristics of the series connected magnetic amplifier were obtained with a load resistor of 48 ohms d.c., measured at room temperature. The exciting voltage was supplied by a 400 cycle generator through an isolation transformer and variac. At zero control current, the variac was adjusted for the

desired voltage, the exciting voltage recorded, and the variac setting held constant while the control current was varied and the corresponding load current recorded. There was a slight drop in exciting voltage as the load current was increased, but as the voltage could not be maintained exactly with the variac, it was decided not to change the variac setting during a "constant" voltage test run. Control characteristics were obtained for the following circuit configurations.

a. Capacitor in series with control windings.

(1) Uncompensated different cores.

(2) Compensated different cores.

(3) Compensated different cores with feedback.

b. Capacitor in shunt with control windings.

(1) Different cores.

(a) Uncompensated.

(b) Compensated.

(c) Compensated, with feedback.

(2) Identical cores.

(a) Uncompensated.

(b) Compensated.

(c) Compensated, with feedback.

Equivalent plate characteristics were obtained with zero load resistance by setting a constant control current, varying exciting voltage with the variac, and recording the corresponding load current. Identical cores with the capacitor in shunt with the control windings were used to obtain equivalent plate characteristics.

A detailed description of the components used in the test circuit is contained in Appendix III.

4. Method of Analysis.

Control characteristics obtained by test were plotted, and the plots were compared. For convenience in comparison, the figures were numbered such that the higher figure number indicates more feedback than the lower. The alphabetic notation following the figure number indicates the configuration. For example, 2a, 3a, and 6a are all different cores with the capacitor in series with the control windings.

Superimposed plots of the equivalent plate characteristics of Deltamax, Permalloy, and Supermalloy were made at zero bias and 200 ampere-turns bias. The average ampere-turns of various configurations at various voltages for these two bias conditions were plotted on the plate characteristics.

The range of linear control, arbitrarily defined as the difference between the maximum and minimum load ampere-turns which differed from the theoretical ampere-turns, i.e., $N_L I_L = N_c I_c$, by plus or minus eight ampere-turns, was plotted versus exciting voltage for various configurations.

The graphical data was then analyzed on the basis of the effects produced by each configuration.

Photographs of the magnetic properties of the components used and other phenomena were made using an oscilloscope and camera.

5. The Effect of Unbalanced Cores.

Fig. 2a is the control characteristic of a series connected magnetic amplifier without a shunt capacitor in the control circuit having cores of different magnetic properties. Hence, $N_1\phi_1'$ is not equal to $N_2\phi_2'$. From equation (12), an alternating current must exist in the control circuit. This alternating current acts as additional biasing current and causes the total bias current to vary both in magnitude and phase with the load current. This condition could also be viewed from a constant control current with a variable feedback current. In either case, the output of the load circuit would differ from that of a balanced amplifier and would be expected to be erratic as seen in Fig. 2a.

Fig. 3a is the control characteristic of the same circuit as Fig. 2a, except that now a shunt capacitor is across the control windings. Fig. 6a is the circuit of Fig. 3a with both cores of Deltamex, i.e., nearly matched cores. Comparing Fig. 3a and Fig. 6a, it can be seen that a load current flows with no control current with mismatched cores while the load current is very nearly zero with matched cores. This is caused by one core, in this case Permalloy, becoming saturated before the other core. It is not correct to say that mismatch causes large load currents to flow with no control current. If the exciting voltage is increased sufficiently to produce a current large enough to saturate both cores in a perfectly balanced amplifier, a relatively large load current would flow at zero control current. Where the effect of mismatch in this phenomenum is important is in the design of an

amplifier using the averaged characteristics of several identical cores. Should the core actually used in the amplifier be more easily saturated than the average core characteristics predict, a considerable load current may flow with zero control current.

Fig. 9 is a plot of range of control versus voltage. The first two upper case letters indicate the magnetic material of cores 1 and 2 respectively. The third upper case letter, when present, indicates the material of core f, when in the circuit. The word "shunt" indicates that a capacitor is shunting the control windings. By comparing the DP shunt line with the DD shunt line and the DPS shunt line with the DDD shunt line, it can be seen that mismatch has an effect on the range of linear operation. Again, it would be incorrect to say that mismatch decreases the range of operation for the same reasons given in the preceding paragraph.

Fig. 10 is the equivalent plate characteristics of Permalloy obtained by using two identical unmatched cores. Since only the region where the load ampere-turns are nearly horizontal give linear operation, it is readily apparent how much range of control can be lost due to mismatch of identical cores.

Fig. 11 is a photograph of the hysteresis loops of the Permalloy cores used in obtaining the plate characteristics.

6. The Effect of Capacitor Shunting Control Winding.

From equations (14) and (15), it is seen that the rate of change of flux in each core should be equal if a capacitor large enough to provide an effective a.c. short circuit is placed in

shunt with the control windings.

A comparison of Fig. 2a and Fig. 2b shows that the addition of the shunt capacitor linearizes the operation of a magnetic amplifier with unbalanced cores by satisfying the conditions of equations (14) and (15), causing the amplifier to perform as if the cores were balanced. When the most readily saturated core, Permalloy, saturates, the flux in the other core, Deltamax, cannot change, by equation (15). Therefore, though not saturated, the Deltamax core performs as though it were saturated, also.

The effect of the shunt capacitor on a circuit which has already been linearized by a compensating core, may be seen by comparing Fig. 3a with Fig. 3b. It is seen that the load current at zero control current is reduced by the addition of the shunt capacitor.

It was originally assumed that the resistance in the compensating windings was negligible. To explain the action of the shunt capacitor with compensating windings, the voltage equations for the compensating loops are rewritten.

$$N_1\phi_1' = i_1 r_1 + N_1\phi_f' \tag{16}$$

$$N_2\phi_2' = i_2 r_2 + N_2\phi_f' \tag{17}$$

If $N_1 = N_2$ and $r_1 = r_2$,

$$N_2\phi_2' - N_1\phi_1' = (i_2 - i_1) r_1 \tag{18}$$

Assume, momentarily, that $N_2\phi_2' - N_1\phi_1'$ is a constant, k.

Next consider the control circuit.

$$N_2\phi_2' - N_1\phi_1' = i_cR_c + q/C \qquad (19)$$

Where C is large, the above equation may be assumed to be approximately correct for both series and shunt configurations if only the pulsating current is of concern. For the series connection, R_c will be large; for the shunt connection, R_c will be small. Having assumed equation (18) to be momentarily constant, the solution of equation (19) in i_c and t is

$$i_c = (k/R_c)(e^{-t/R_cC}) \qquad (20)$$

When $N_2\phi_2'$ is greater than $N_1\phi_1'$, k is positive.

$$i_c' = -(k/R_c^2C)(e^{-t/R_cC}) \qquad (21)$$

In the series connection i_c is small, positive and decreasing slowly; i_c' is small negative and decreasing slowly. Since i_c was taken in the same direction as I_c, the d.c. bias current, decreasing i_c effectively reduces the bias on core 2. Since i_c' is negative the rate of change of flux due to i_c' is decreased in core 2 as i_c' decreases.

The above effects are greater with the shunt connection than the series connection for two reasons. The magnitude of i_c and i_c' are greater due to the smaller resistance in the denominator of equation (20) and (21). The changes can occur more rapidly due to the shorter time constant.

The decrease in load ampere-turns at zero control current and

at low values of control current, as seen in Fig. 3a and Fig. 3b, was due to the desaturating effect of the pulsating component of control current explained above. The same approach can be used to show that the shunt capacitor extends the range of linear control obtainable using the series configuration, as shown in Fig. 9.

7. The Effect of Compensating Core.

Equation (6) states the rate of change of flux in all cores is equal when the compensating core is coupled to the two primary cores with windings having equal turns and no resistance. A comparison of Fig. 2a with Fig. 3a indicates that this is true since the operation appears linear. However, an undesirable effect is noted. The load ampere-turns at zero control current is greater for the compensated amplifier than for the unbalanced series amplifier. This can be explained by equation (6) and equation (9). From equation (6), the rate of change of flux cannot change after one core saturates, since the rate of change of both cores must be equal with compensation. From equation (9), the rates of change of flux may be different. Therefore, the flux in one core may still be changing after the other core has saturated. The reactance in the load circuit exists over a greater portion of a cycle in the unbalanced amplifier, hence, the average load current is less.

Comparing Fig. 3b with Fig. 2b, it is noted that the rise in load current at low values of control current, when the control current is decreased, is eliminated by the addition of the compensating core and windings. That the hump can exist is partially explained by equation (20). The momentary imbalance, k, of the

flux change in cores 1 and 2 would be greater without the compensating circuit since this circuit tends to keep the cores balanced. Therefore, the initial i_c would be larger causing the initial bias on both cores to be larger. Equation (20) is based on an assumption that k is constant, which is not true, and can only be used qualitatively. Placing the compensating core in the circuit reduces the value of k, and thus i_c, which reduces the initial bias. Increasing the d.c. bias reduces the total amount of flux per cycle of operation. If the rate of change of flux in each core were reduced by the same fraction when the d.c. bias were increased, the value of k would be reduced by this fraction. The average bias is produced by the direct current, I_c, and the pulsating current, i_c, in the control circuit. Since an increase in I_c reduces k, it also reduces the value of i_c. When the value of I_c is small, i_c can be large and the bias due to the average i_c large. As I_c is increased the average bias due to a small increase in I_c is greater than the debiasing due to the decrease in i_c. At some value of I_c, a further increase in the value of I_c, so reduces the value of i_c, that the increase bias due to I_c is less than the debiasing effect due to the decrease in i_c, and the result is an effective debias. This value of I_c is that corresponding to the peak of the humps in the curves of Fig. 2b. That these humps are caused by the pulsating component in the control circuit is shown by Fig. 3b. The compensating core is now in the circuit, and currents i_1 and i_2 can flow. From equation (6), it is seen that this would reduce the value of k, thereby reducing the value

of i_c. Since reducing i_c eliminates the humps of Fig. 2b, as shown by Fig. 3b, it is concluded that these humps were caused by large values of pulsating current in the control circuit, and can be eliminated by use of the compensating core.

From Fig. 9, it can be seen that the addition of a compensating core also increases the range of linear control.

8. The Effect of Magnetic Feedback.

Fig. 3 through Fig. 6 show the effect of increasing magnetic feedback on the control characteristics of a magnetic amplifier. The observed results appear to be identical with the results obtained by other feedback methods and agree exactly, within the accuracy of measurements, with results predicted by theory. Theoretically

$$2N_L I_L = 2N_c I_c + N_f I_L \tag{22}$$

$$(2N_L - N_f) I_L = 2N_c I_c \tag{23}$$

Substitution of values from the linear range of the control characteristics into equation (23) satisfy the equation.

In Fig. 6c, it is noted that appreciable load current flows at zero control current at 80 volts RMS, a condition which did not exist without feedback. Refer to Fig. 14, the plate characteristics of Deltamax. Load line "a" is the load line at 80 volts average without feedback and 2,000 turns in the load circuit. Load line "c" is the load line at 80 volts average with 500 turns feedback and 2,000 load turns in the load circuit. The effective

turns in the load circuit are 2,000 - 500 or 1,500 turns. It is this value which must be used for N_L in the fraction Ea/N_L to obtain the proper voltage from which to draw the load line. The load line is seen to be around the knee of the zero control characteristic and intersects it at 134 ampere-turns load current. The load ampere-turns without feedback were only 8. It is seen that the load current at zero control current is normal, and is due to too large a voltage for the amount of feedback used, and is not an adverse effect due to the method of obtaining the feedback.

9. Overall Effect.

Consider Fig. 12a, the plate characteristics of Permalloy and Deltamax at zero control current, on which the values of $2N_L I_L$ versus $E_a/2N_L$ for the series and shunt configurations, without compensation have been plotted. It appears that the Permalloy core is the controlling core with the shunt connection, and both cores share control with the series connection. This was predicted earlier in section 6, since Permalloy is the most easily saturated core. Fig. 12b, a plot of the compensated series and shunt configuration characteristics with and without feedback at zero current control show that Permalloy is again the controlling core in the shunt configuration. It also shows that the voltage range over which linear operation is obtained is reduced by feedback.

Fig. 13a is a plot of the characteristics of the uncompensated series and shunt configurations at 200 ampere-turns d.c. bias. It is seen that nowhere is the operation linear for the series configuration. Again, Permalloy is the controlling core, with the

shunt capacitor permitting linear operation over the full range of the Permalloy characteristic. Fig. 13b is a plot of the compensated circuits of Fig. 13a with and without feedback. In the series configuration it is seen that Supermalloy seems to be the controlling core indicating that it saturates before either Deltamax or Permalloy. Feedback has a demagnetizing effect on core f. With feedback it appears that Permalloy and Deltamax share the control indicating that Permalloy and Deltamax are saturating before Supermalloy, which is known to have less bias.

In the shunt configuration Permalloy is the controlling core. Since i_c is greater with the shunt connection, i_1 and i_2 must be smaller. Therefore, Supermalloy does not saturate. Feedback reduces the voltage range for linear operation which is normal.

Fig. 14 is an oscillograph of the voltage drop across the load resistor with the series configuration showing both compensated and uncompensated wave forms. The balancing effect of the compensating core is apparent.

10. Conclusions.

A shunt capacitor is necessary for a wide range of linear operation if the mismatch is very large.

A shunt capacitor is always desirable because of its matching tendency.

A compensating core tends to correct the effects of mismatch, but is more effective when used with a shunt capacitor.

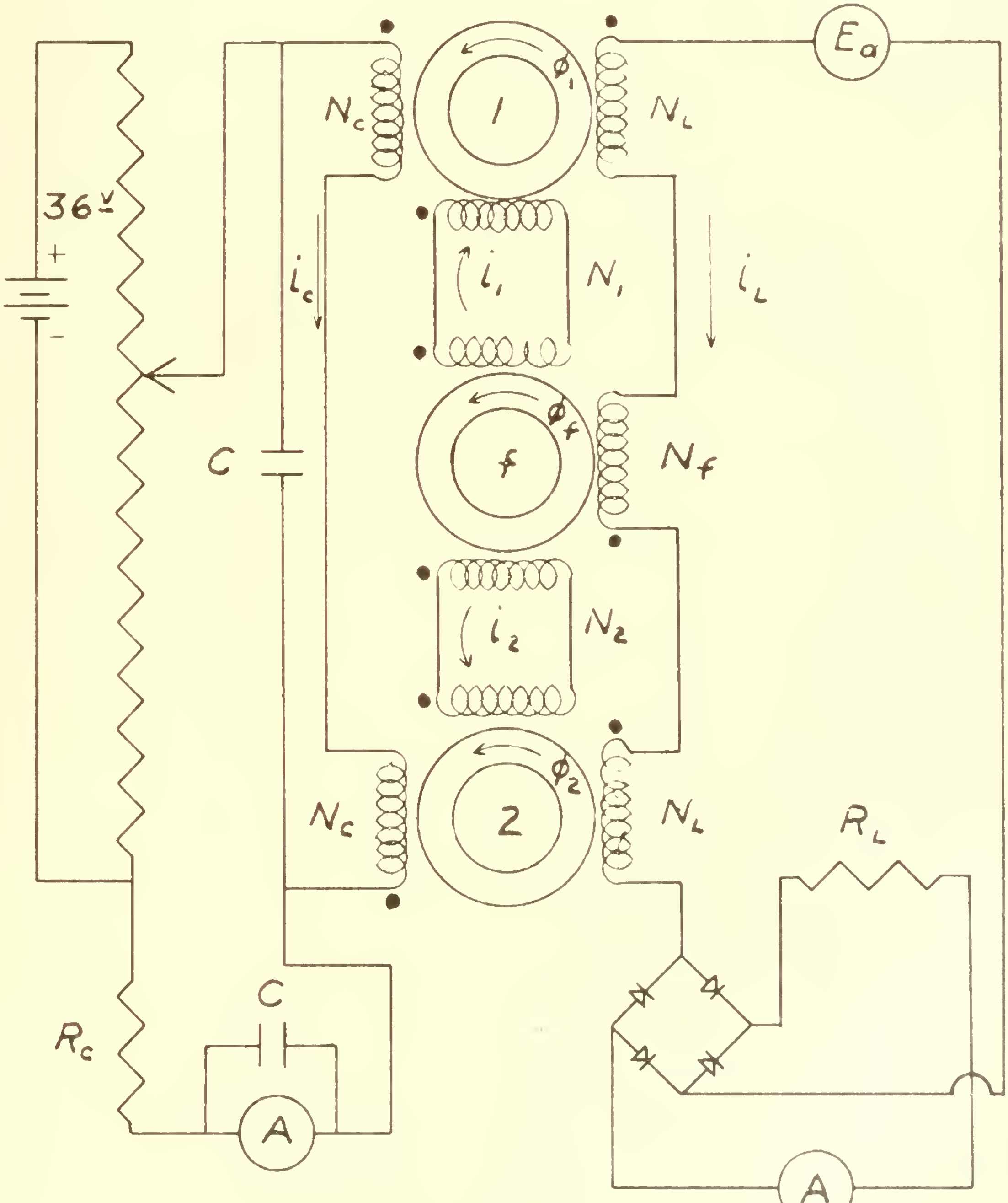
A compensating core eliminates the tendency toward rising load current with decreasing control current which was found in the uncompensated shunt configuration.

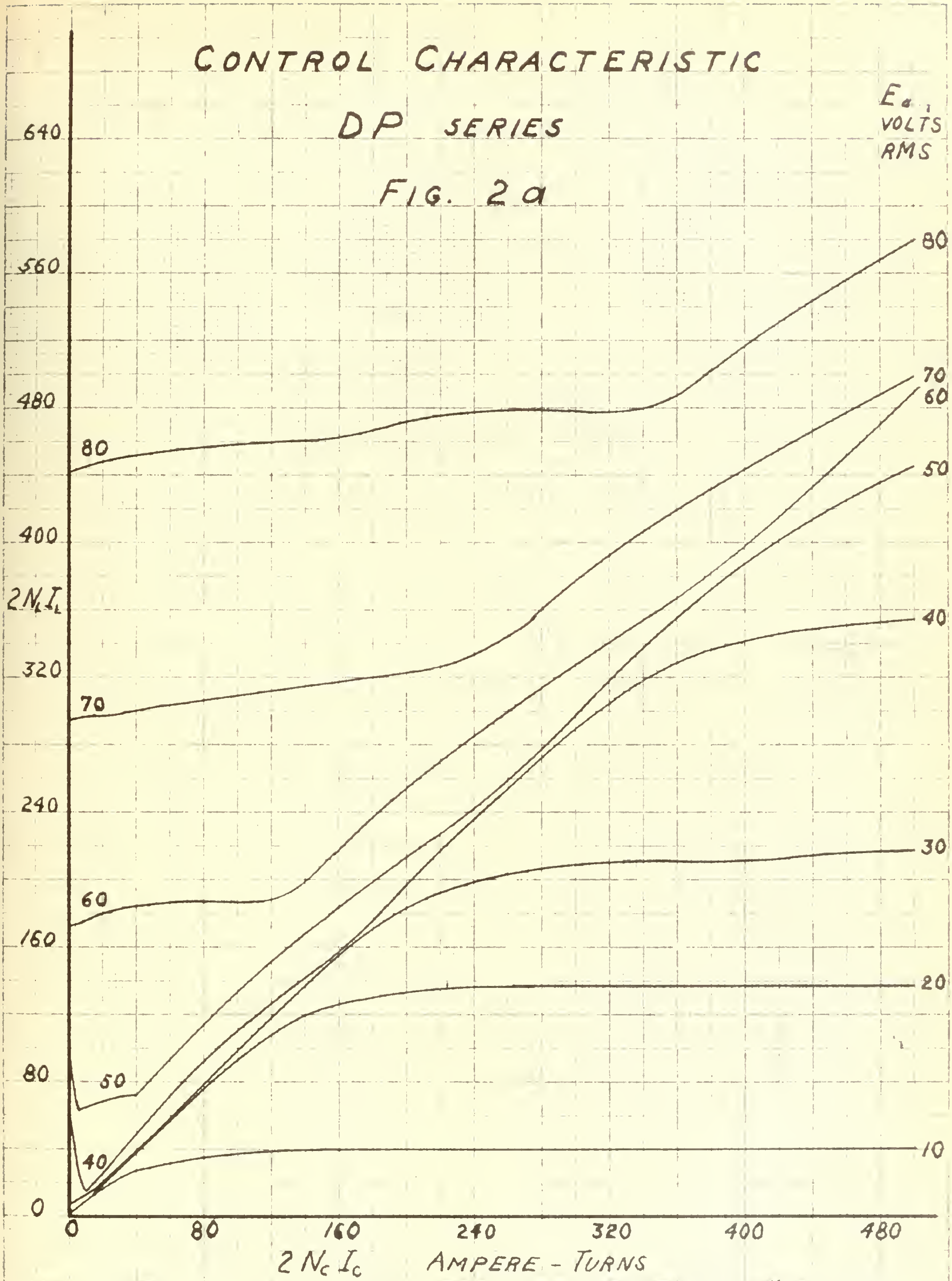
A compensating core is effective in extending the range of linear operation by 15% to 20%.

A compensating core is effective as a feedback device.

SERIES CONNECTED MAGNETIC AMPLIFIER WITH MAGNETIC COMPENSATION

FIG. 1



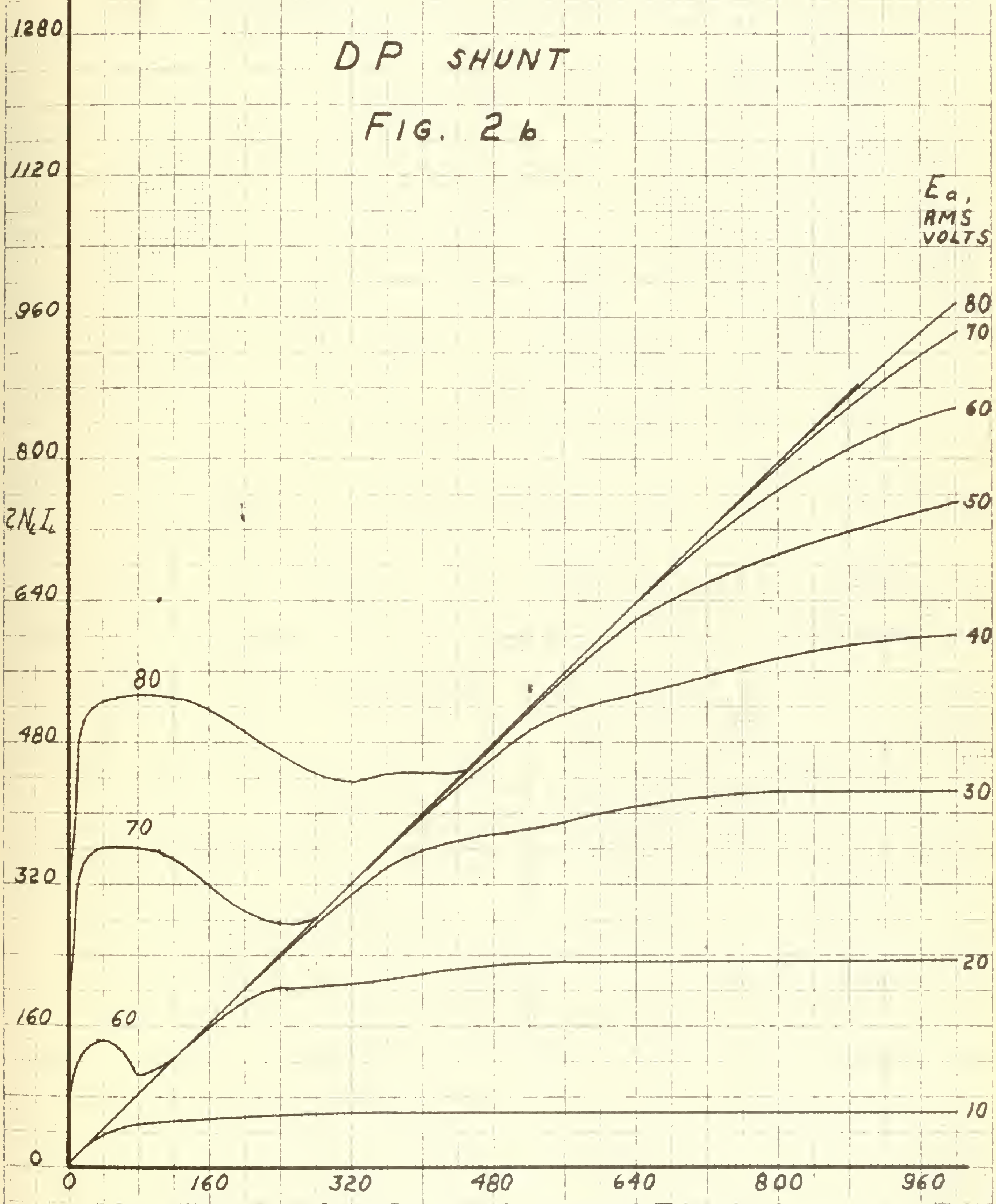


E_a = 400 cps ; $2N_L$ = 1,000 ; $N_1 = N_2$ = NONE ; CORE #1 = D1-2
R_L = 48 Ω ; $2N_c$ = 1,000 ; N_f = NONE ; CORE 2 = P1-2
CORE f = NONE

CONTROL CHARACTERISTIC

DP SHUNT

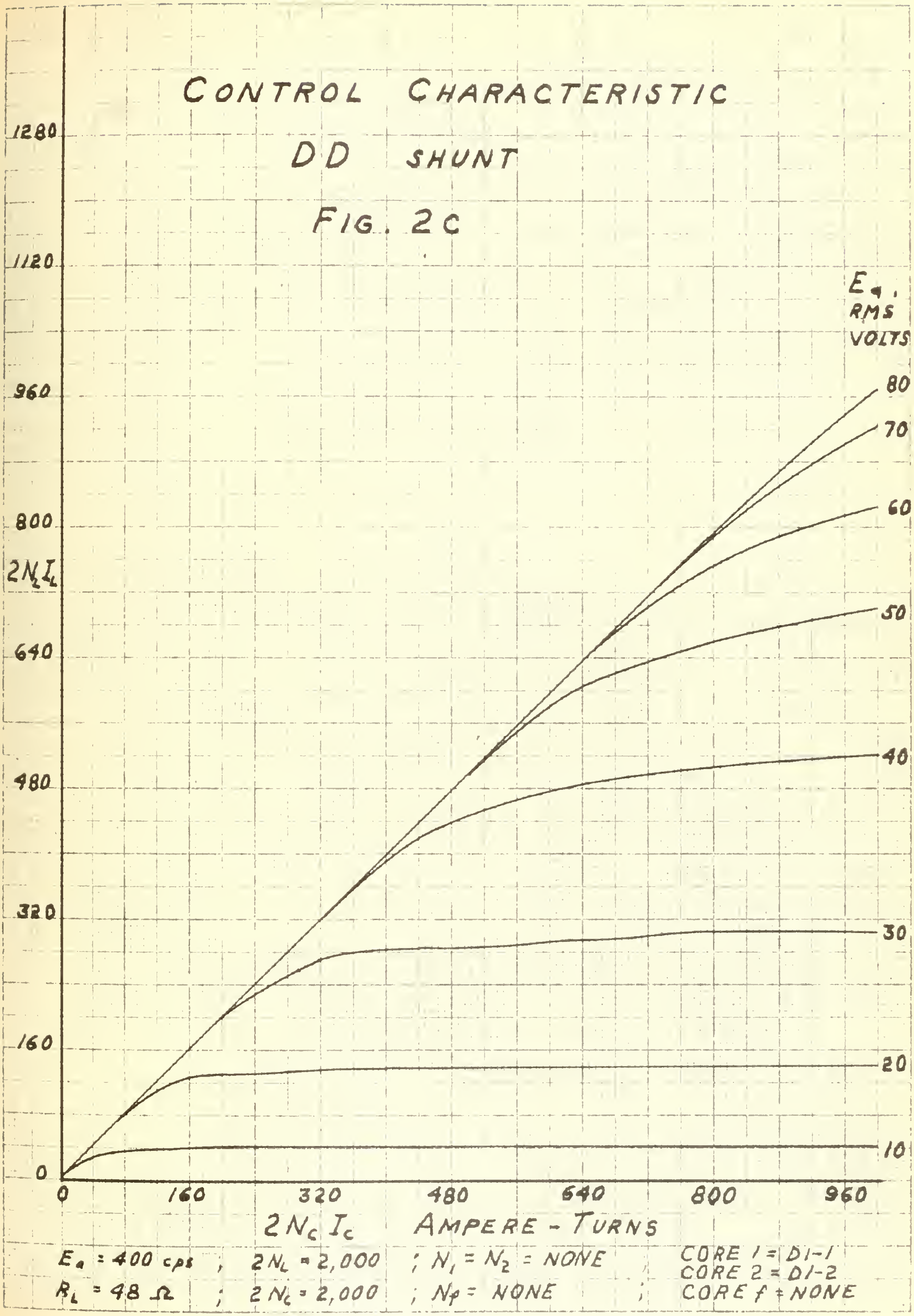
FIG. 2b



E_a = 400 cps ; $2N_L$ = 2,000 ; $N_1 = N_2$ = NONE ; CORE 1 = D1-2

R_L = 48 Ω ; $2N_c$ = 2,000 ; N_f = NONE ; CORE 2 = P1-2

CORE f = NONE

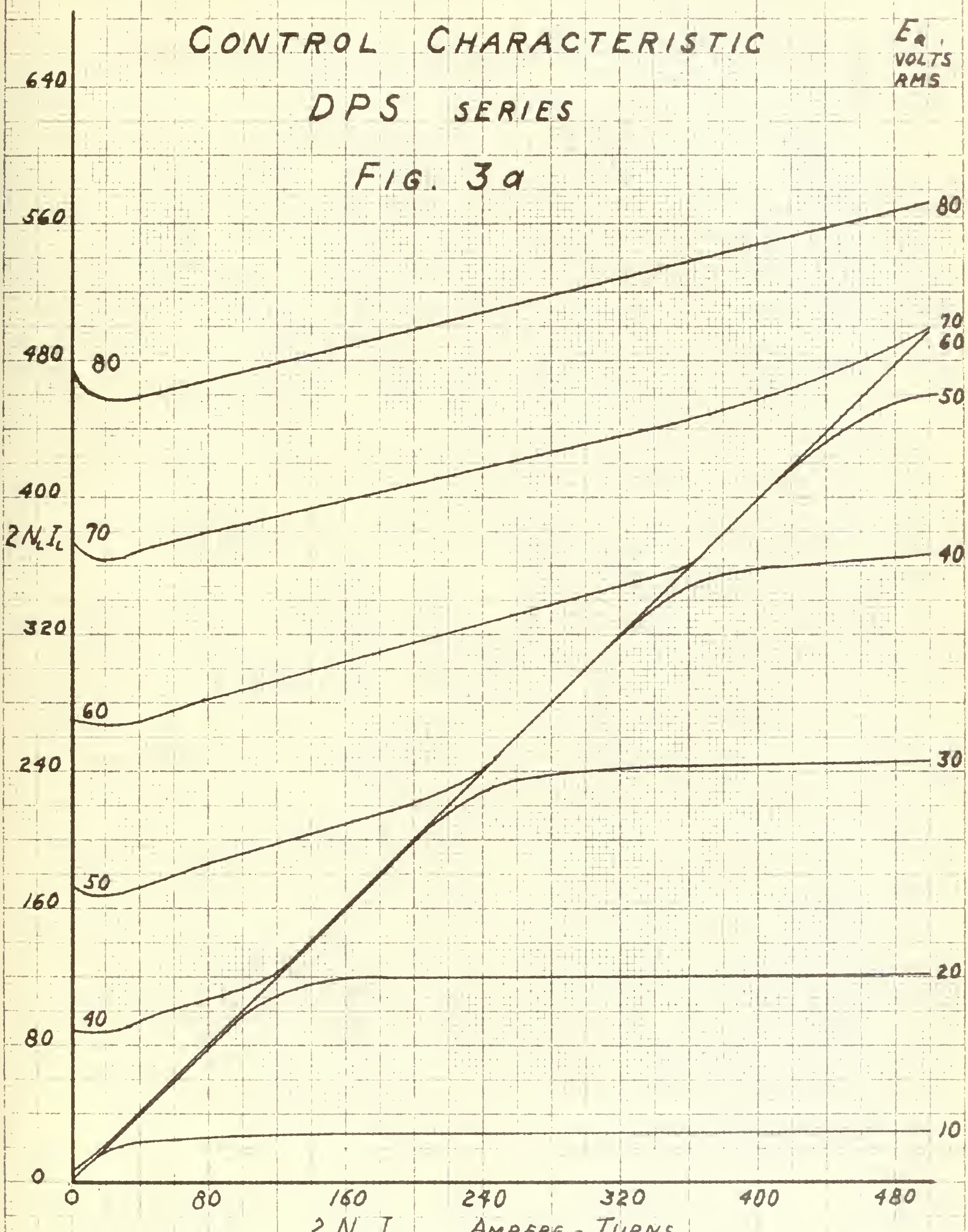


CONTROL CHARACTERISTIC
DD SHUNT
FIG. 2C
1280
1120
960
800
640
480
320
160
0
$2N_L I_L$
E_a, RMS VOLTS
80
70
60
50
40
30
20
10
0
160
320
480
640
800
960
$2N_c I_c$ AMPERE - TURNS
E_a = 400 cps ; $2N_L$ = 2,000 ; $N_1 = N_2$ = NONE ; CORE 1 = D1-1
CORE 2 = D1-2
R_L = 48 Ω ; $2N_c$ = 2,000 ; N_f = NONE ; CORE f = NONE

CONTROL CHARACTERISTIC

DPS SERIES

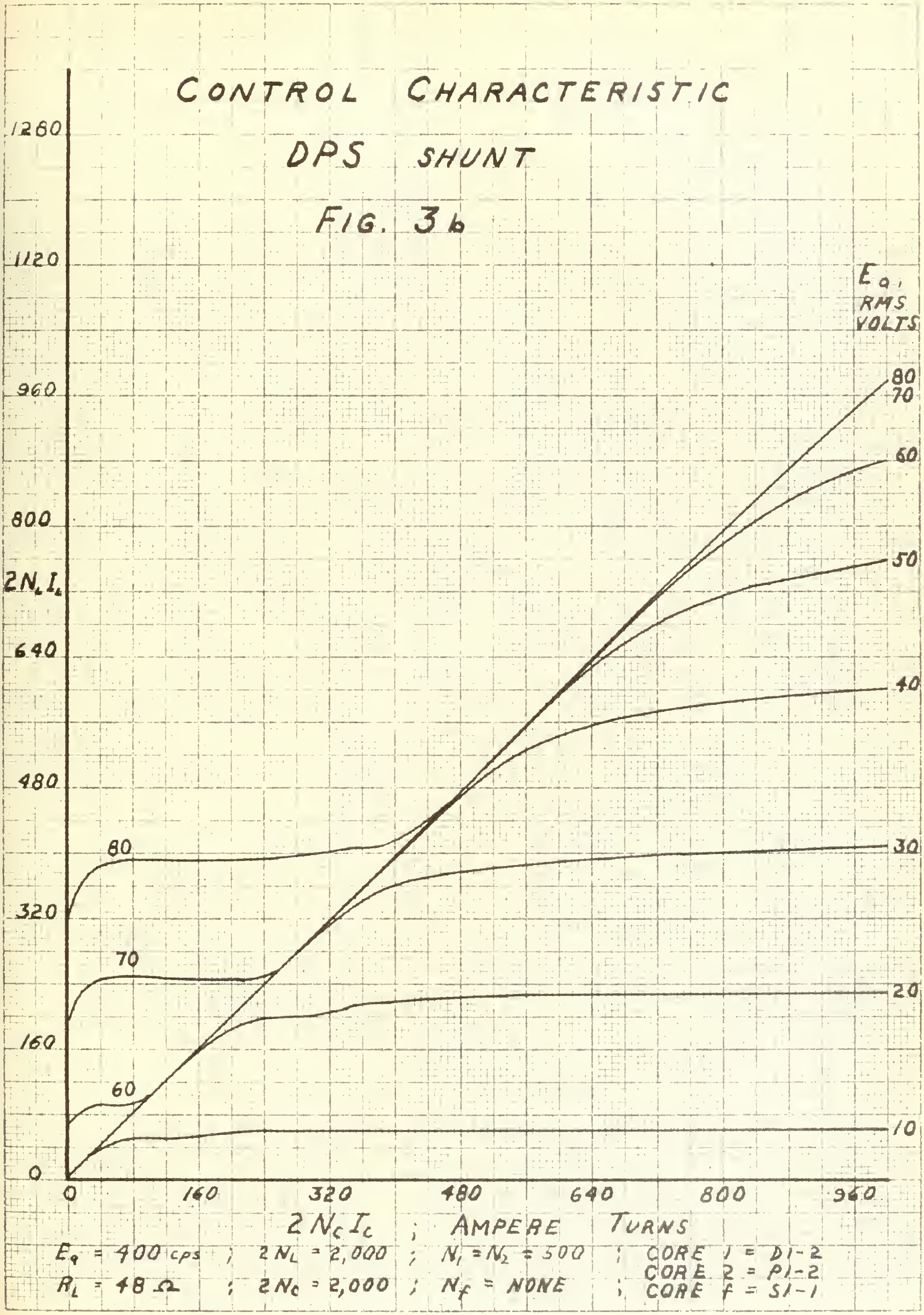
FIG. 3a

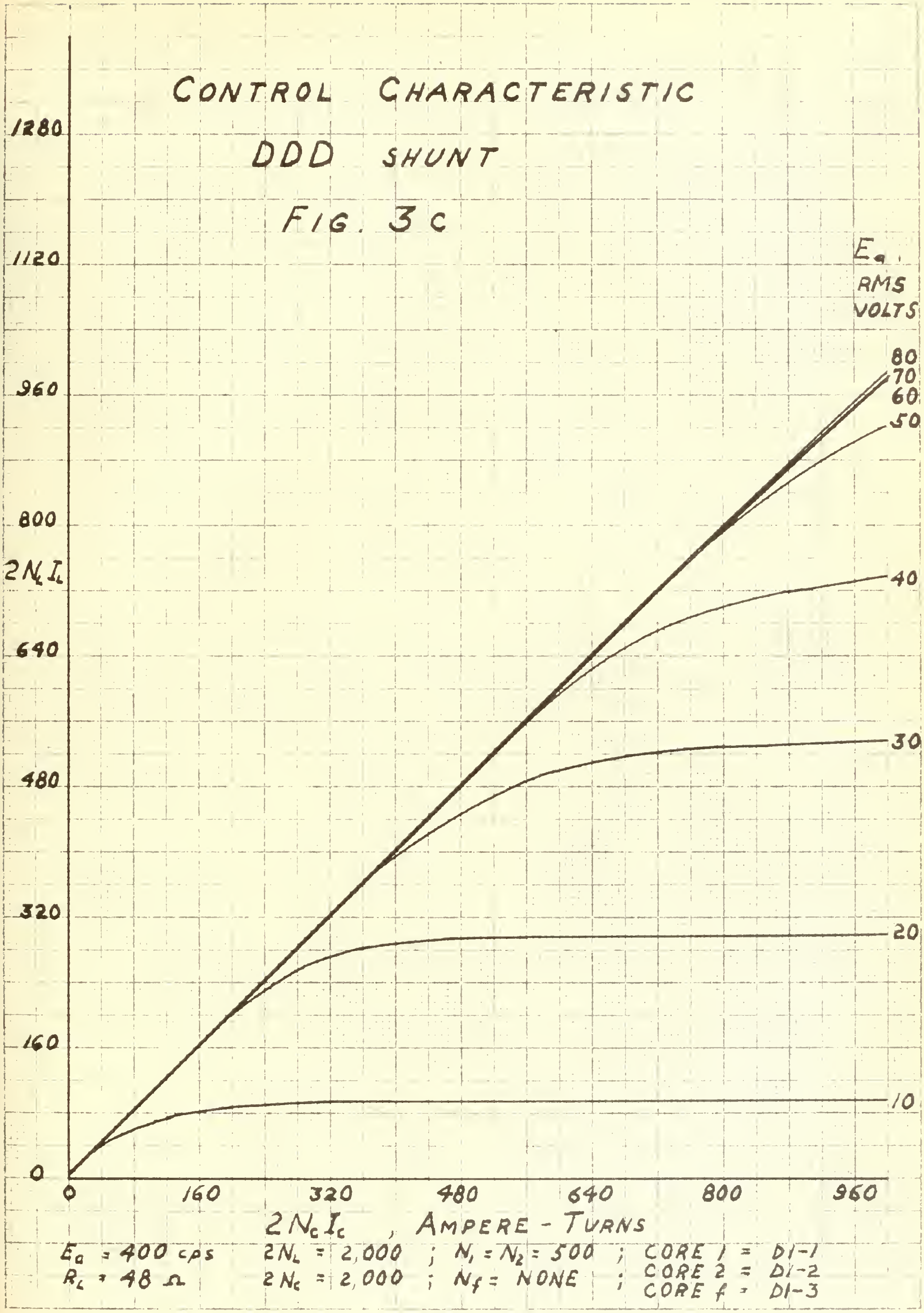


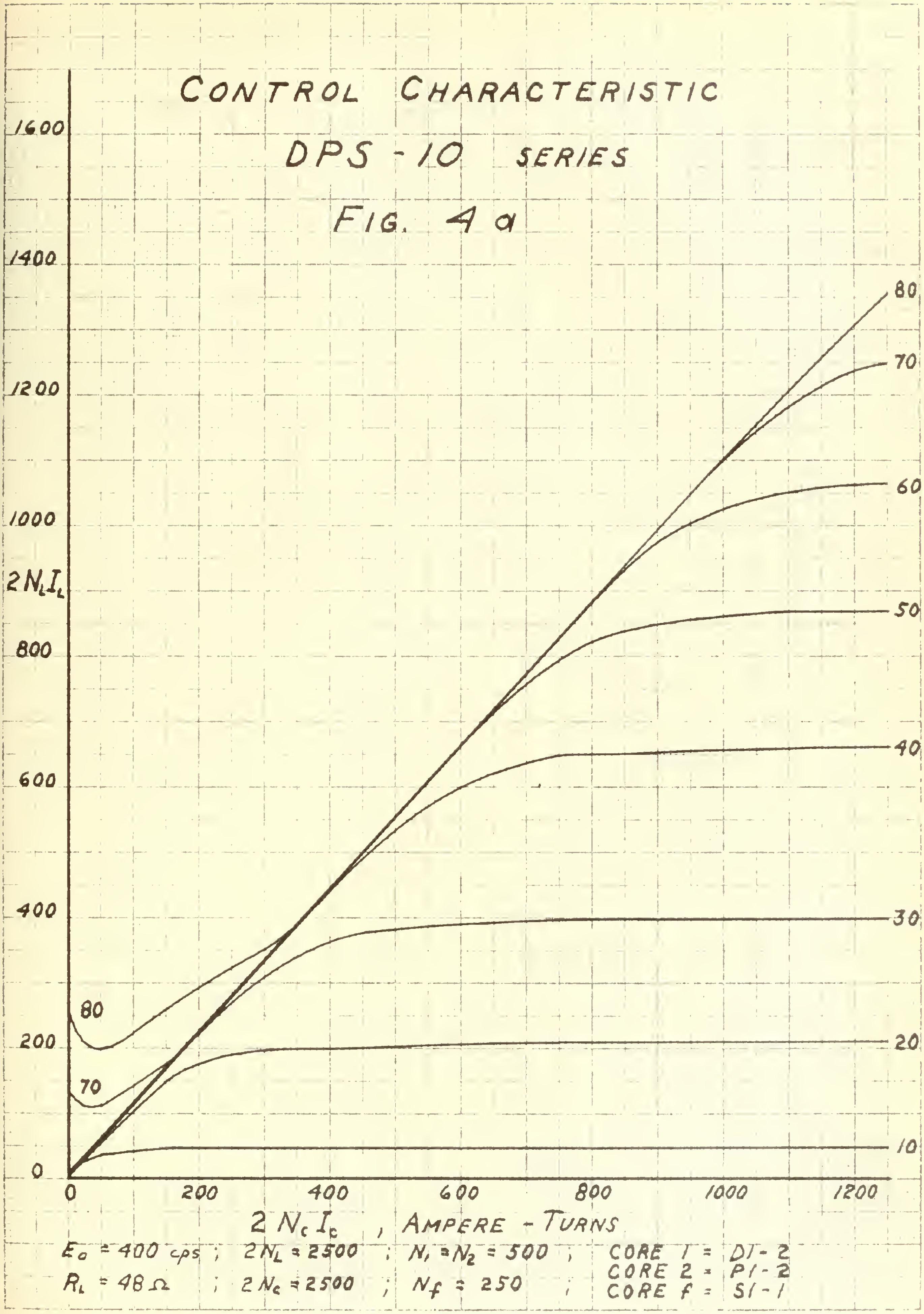
E_a = 400 cps ; $2N_L$ = 1,000 ; $N_1 = N_2$ = 500 ; CORE 1 = DI-2

R_L = 48 Ω ; $2N_c$ = 1,000 ; N_f = NONE ; CORE 2 = PI-2

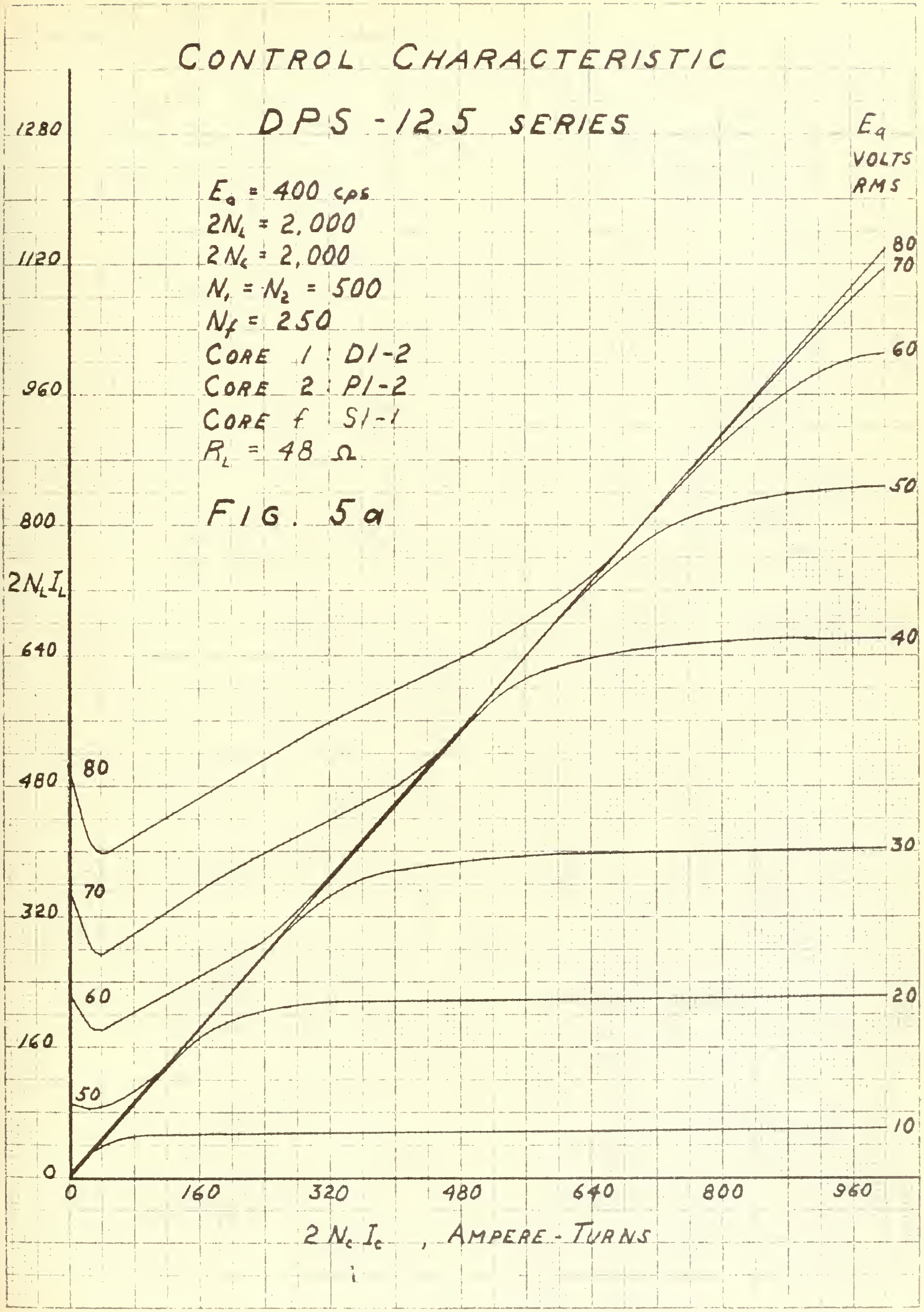
CORE f = SI-1


CONTROL CHARACTERISTIC
DPS SHUNT
FIG. 3b
1280
1120
960
800
$2N_L I_L$
640
480
320
160
0
80
70
60
E_q, RMS VOLTS
80
70
60
50
40
30
20
10
0
160
320
480
640
800
960
$2 N_c I_c$; AMPERE TURNS
E_q = 400 cps ; $2N_L$ = 2,000 ; $N_1 = N_2$ = 500 ; CORE 1 = DI-2
CORE 2 = PI-2
R_L = 48 Ω ; $2N_c$ = 2,000 ; N_f = NONE ; CORE f = SI-1


CONTROL CHARACTERISTIC
DDD SHUNT
FIG. 3c
E_a, RMS VOLTS
80
70
60
50
40
30
20
10
1280
1120
960
800
640
480
320
160
0
$2N_L I_L$
0
160
320
480
640
800
960
$2N_c I_c$, AMPERE - TURNS
E_a = 400 cps
R_L = 48 Ω
$2N_L$ = 2,000 ; $N_1 = N_2$ = 500 ; CORE 1 = DI-1
$2N_c$ = 2,000 ; N_f = NONE ; CORE 2 = DI-2
CORE f = DI-3



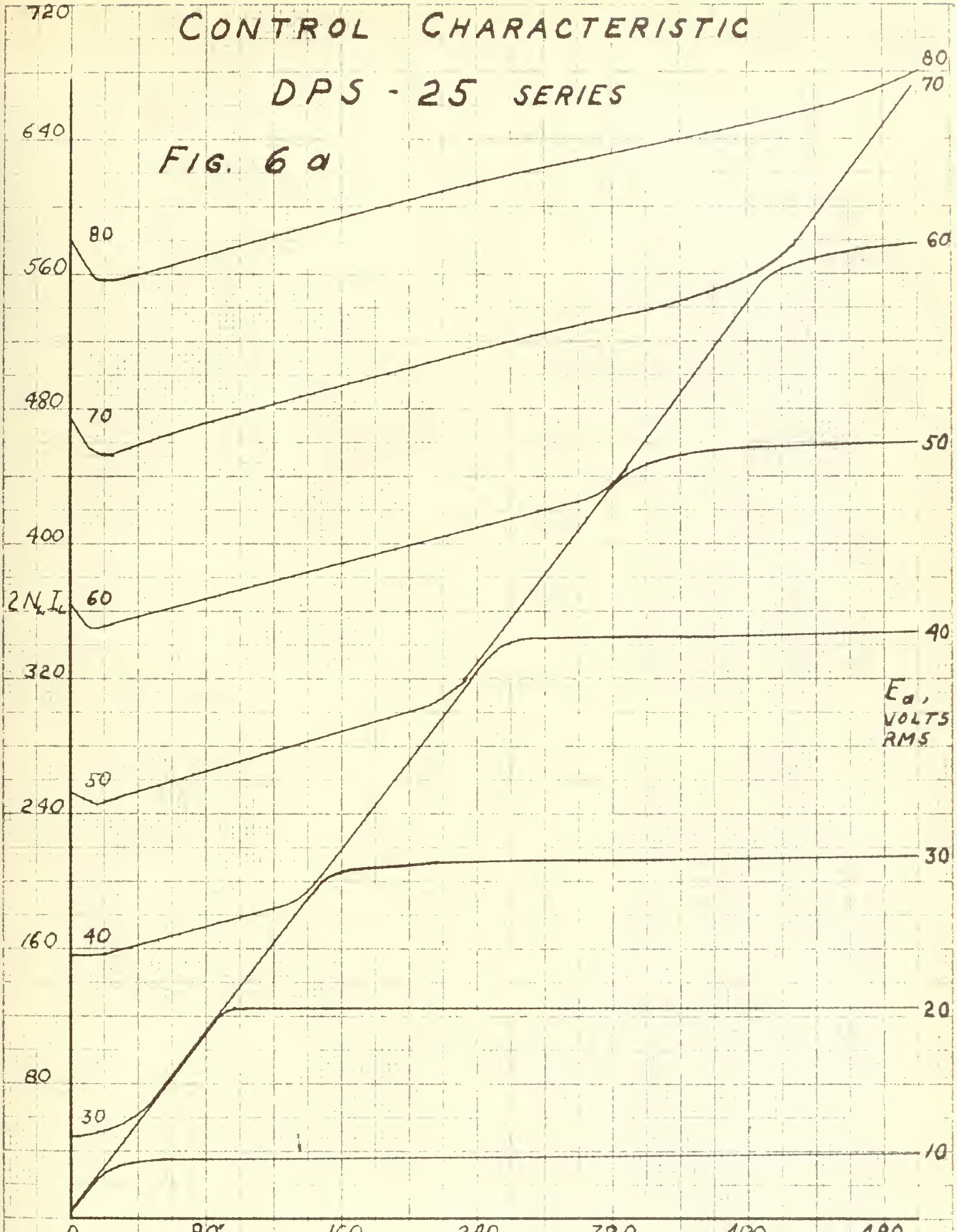
CONTROL CHARACTERISTIC
DPS - 10 SERIES
FIG. 4 a
1600
1400
1200
1000
$2N_L I_L$
800
600
400
200
0
80
70
60
50
40
30
20
10
80
70
0
200
400
600
800
1000
1200
$2 N_c I_c$, AMPERE - TURNS
E_o = 400 cps ; $2N_L$ = 2500 ; $N_1 = N_2$ = 500 ; CORE 1 = DI-2
R_L = 48 Ω ; $2N_c$ = 2500 ; N_f = 250 ; CORE 2 = PI-2
CORE f = SI-1


CONTROL CHARACTERISTIC
DPS-12.5 SERIES
E_a = 400 cps
$2N_L$ = 2,000
$2N_c$ = 2,000
$N_1 = N_2$ = 500
N_f = 250
CORE 1 D1-2
CORE 2 P1-2
CORE f S1-1
R_L = 48 Ω
FIG. 5a
E_a VOLTS RMS
$2N_L I_L$
$2N_c I_c$, AMPERE-TURNS
1280
1120
960
800
640
480
320
160
0
160
320
480
640
800
960
80
70
60
50
40
30
20
10

CONTROL CHARACTERISTIC

DPS - 25 SERIES

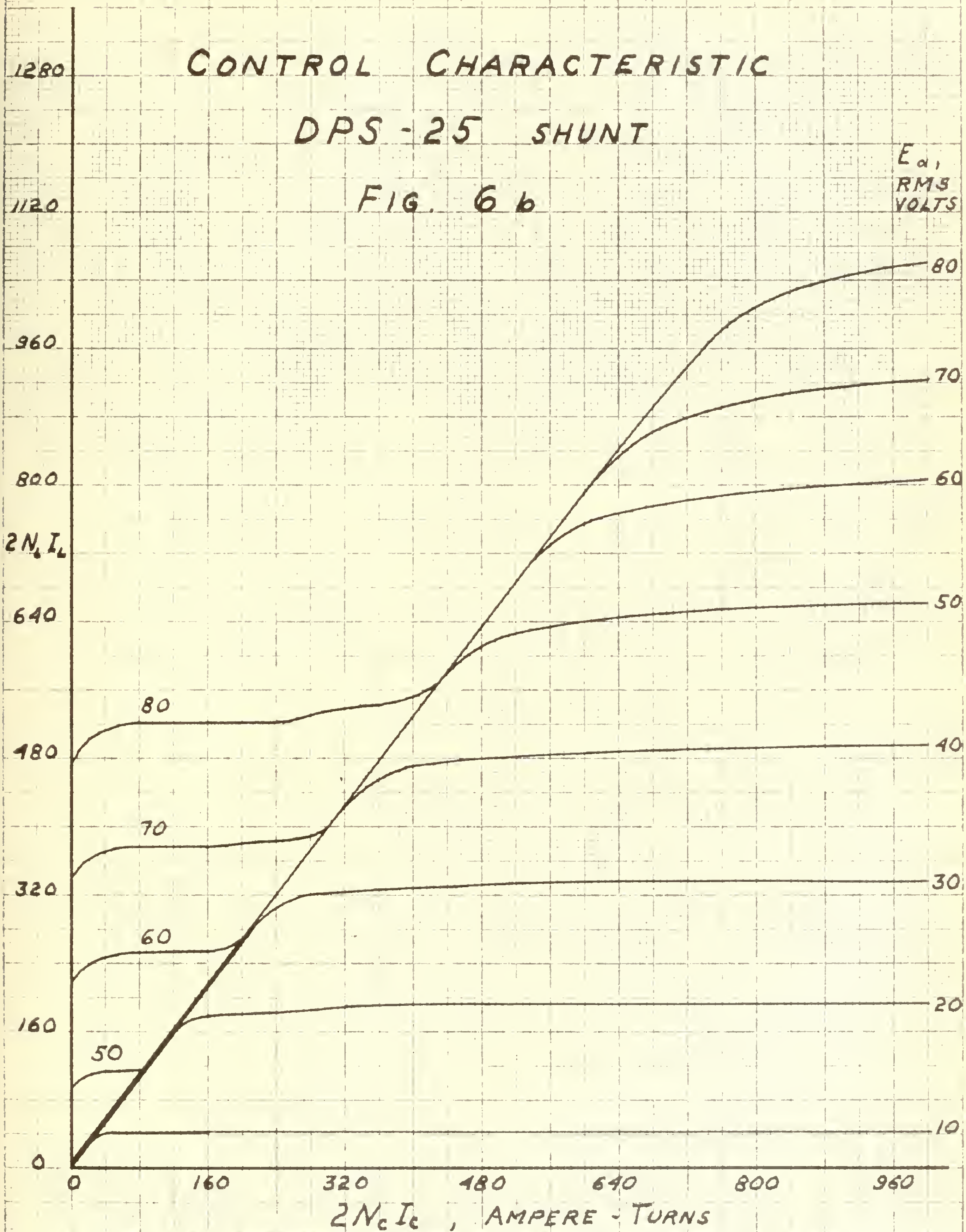
FIG. 6 a



$2N_cI_c$, AMPERE TURNS

E_a = 400 CPS $2N_L$ = 1,000 $N_1 = N_2$ = 500 CORE 1 = DI-2
R_L = 48 Ω $2N_c$ = 1,000 N_f = 250 CORE 2 = PI-2
CORE f = SI-1

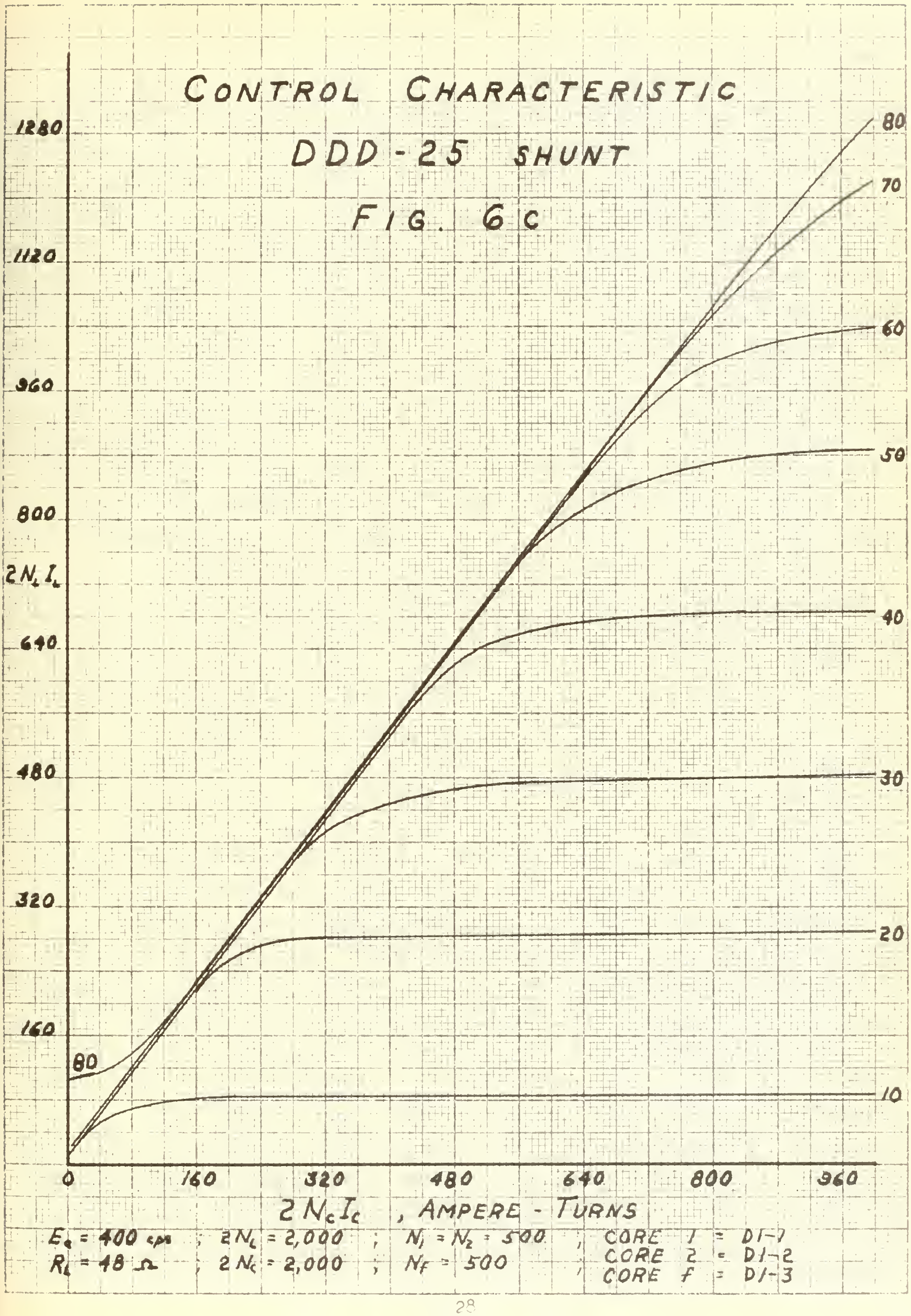
CONTROL CHARACTERISTIC
DPS-25 SHUNT
FIG. 6b

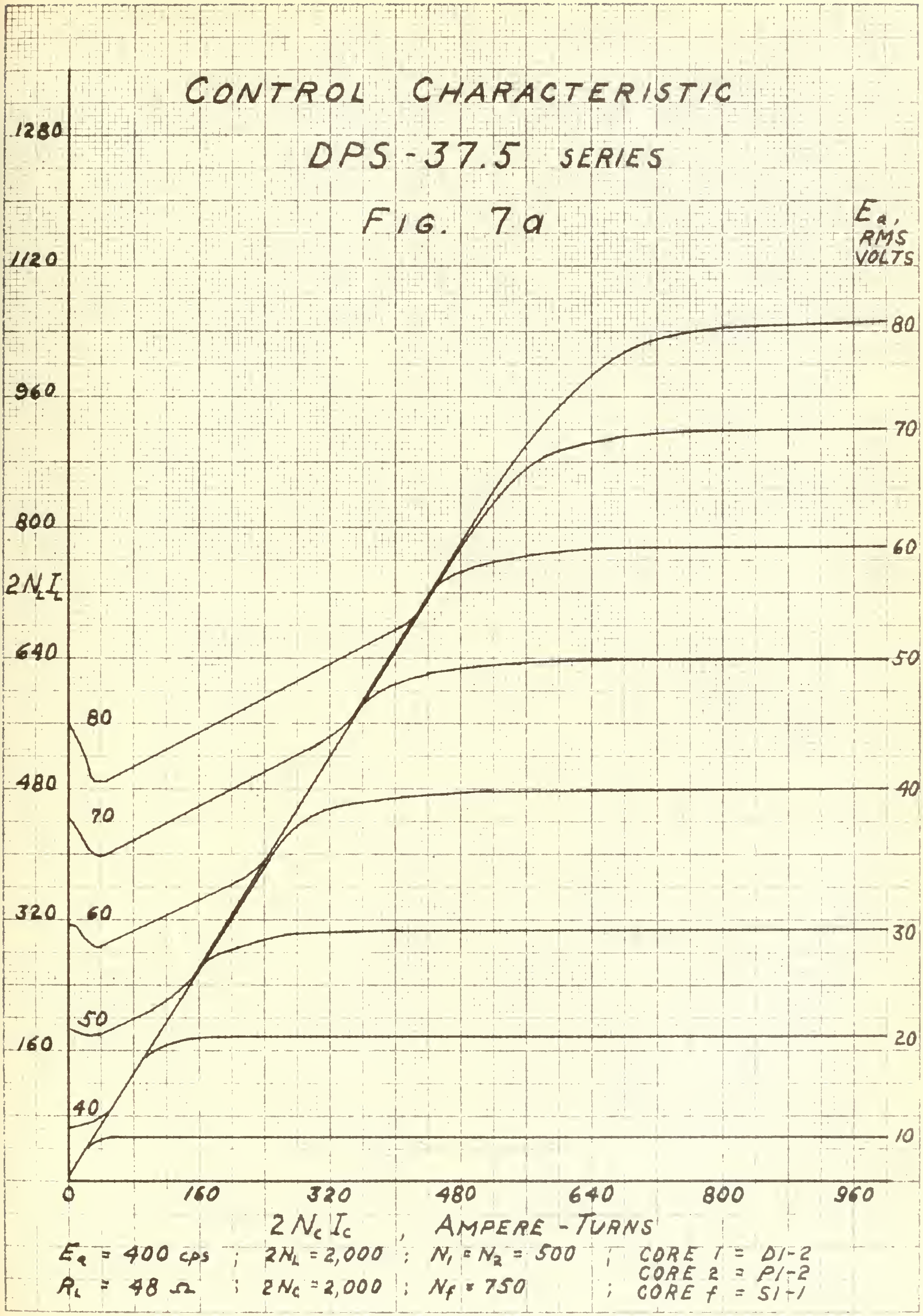


E_a = 400 cps ; $2N_L$ = 2,000 ; $N_1 = N_2$ = 500

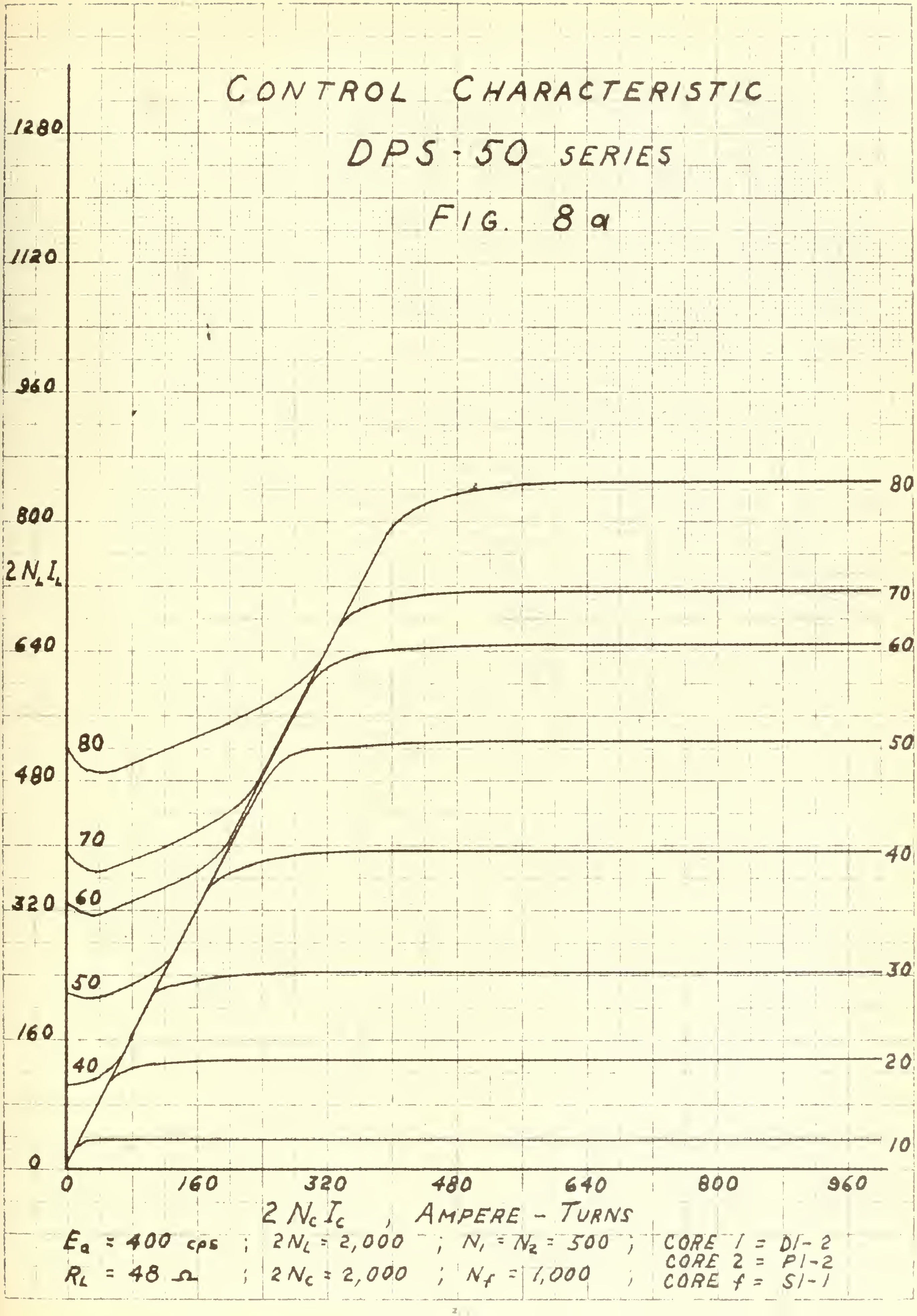
R_L = 48 Ω ; $2N_c$ = 2,000 ; N_f = 500

CORE 1 = DI-2
CORE 2 = PI-2
CORE f = SI-1


CONTROL CHARACTERISTIC
DDD-25 SHUNT
FIG. 6c
1280
1120
960
800
$2N_L I_L$
640
480
320
160
80
0
160
320
480
640
800
960
80
70
60
50
40
30
20
10
$2N_cI_c$, AMPERE - TURNS
E_a = 400 cps ; $2N_L$ = 2,000 ; $N_1 = N_2$ = 500 ; CORE 1 = D1-1
R_L = 48 Ω ; $2N_c$ = 2,000 ; N_F = 500 ; CORE 2 = D1-2
CORE F = D1-3

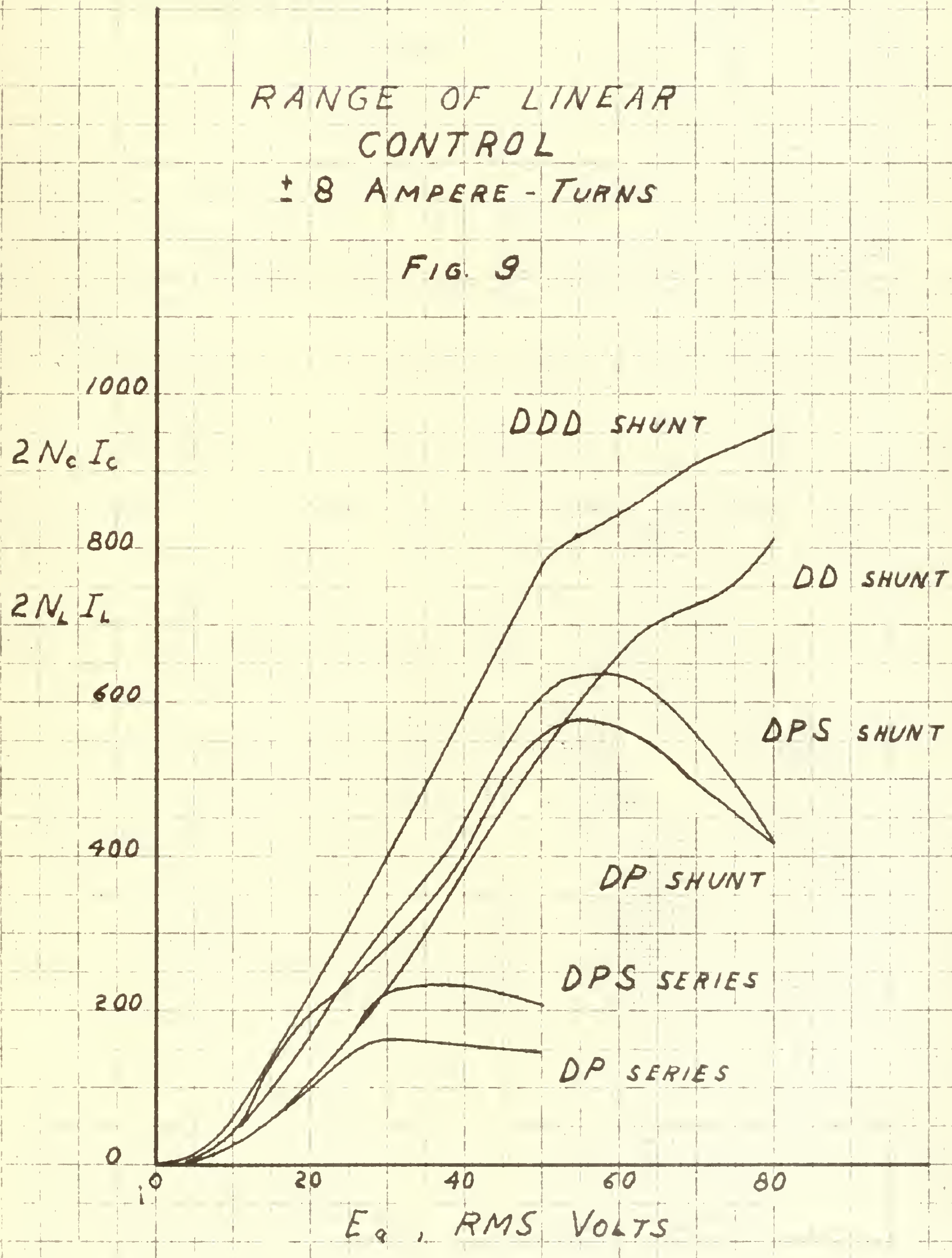


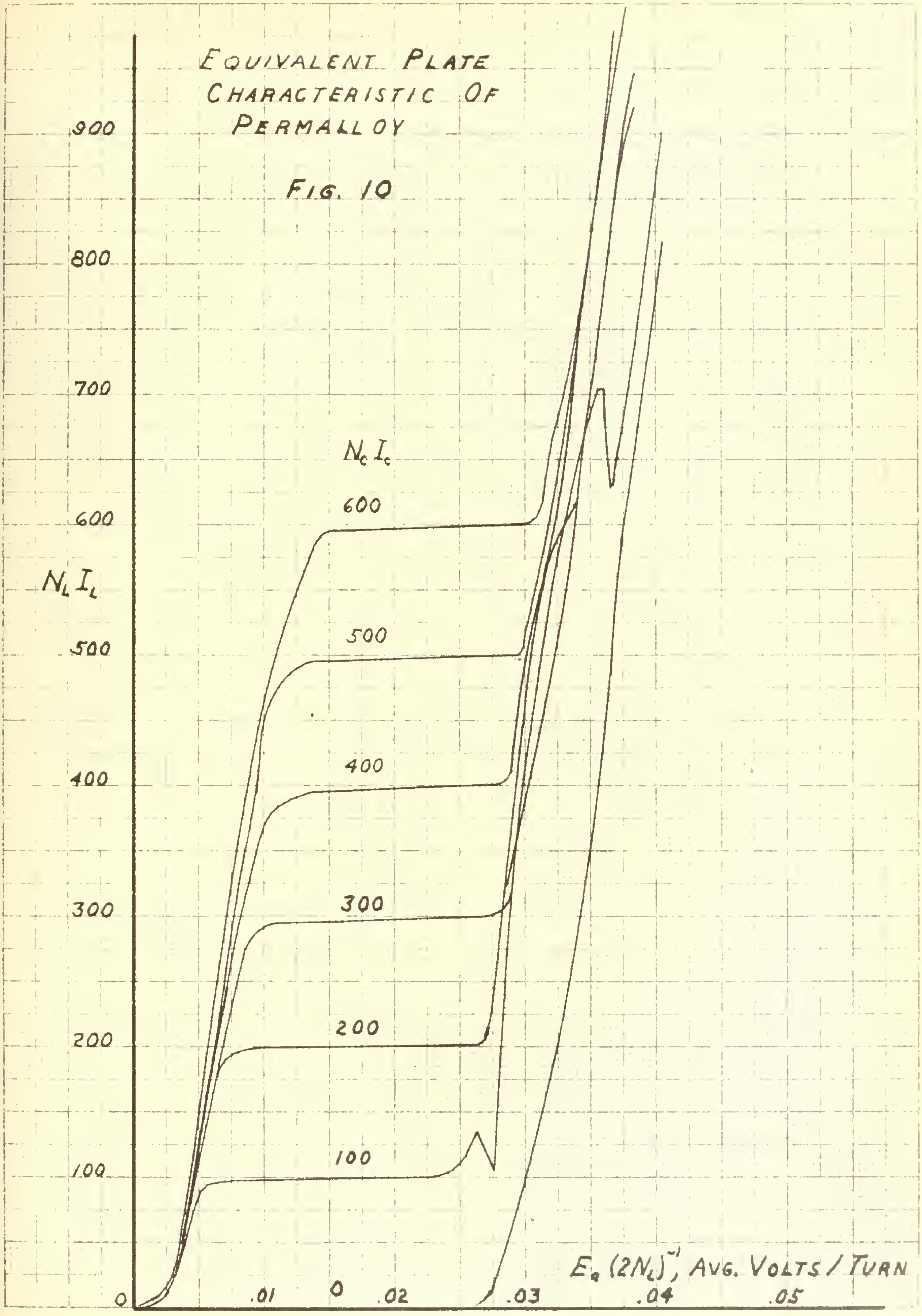
CONTROL CHARACTERISTIC
DPS-37.5 SERIES
FIG. 7a
1280
1120
960
800
2N_L I_L
640
480
320
160
80
70
60
50
40
E_a, RMS VOLTS
80
70
60
50
40
30
20
10
0
160
320
480
640
800
960
2N_c I_c , AMPERE-TURNS
E_a = 400 cps ; 2N_L = 2,000 ; N_1 = N_2 = 500 ; CORE 1 = D1-2
R_L = 48 Ω ; 2N_c = 2,000 ; N_f = 750 ; CORE 2 = P1-2
CORE f = S1-1


CONTROL CHARACTERISTIC
DPS-50 SERIES
FIG. 8a
1280
1120
960
800
$2N_L I_L$
640
480
320
160
0
80
70
60
50
40
30
20
10
0
160
320
480
640
800
960
$2N_c I_c$, AMPERE - TURNS
E_a = 400 cps ; $2N_L$ = 2,000 ; $N_1 = N_2$ = 500 ; CORE 1 = DI-2
R_L = 48 Ω ; $2N_c$ = 2,000 ; N_f = 1,000 ; CORE 2 = PI-2
CORE f = SI-1

RANGE OF LINEAR CONTROL
± 8 AMPERE - TURNS

FIG. 9

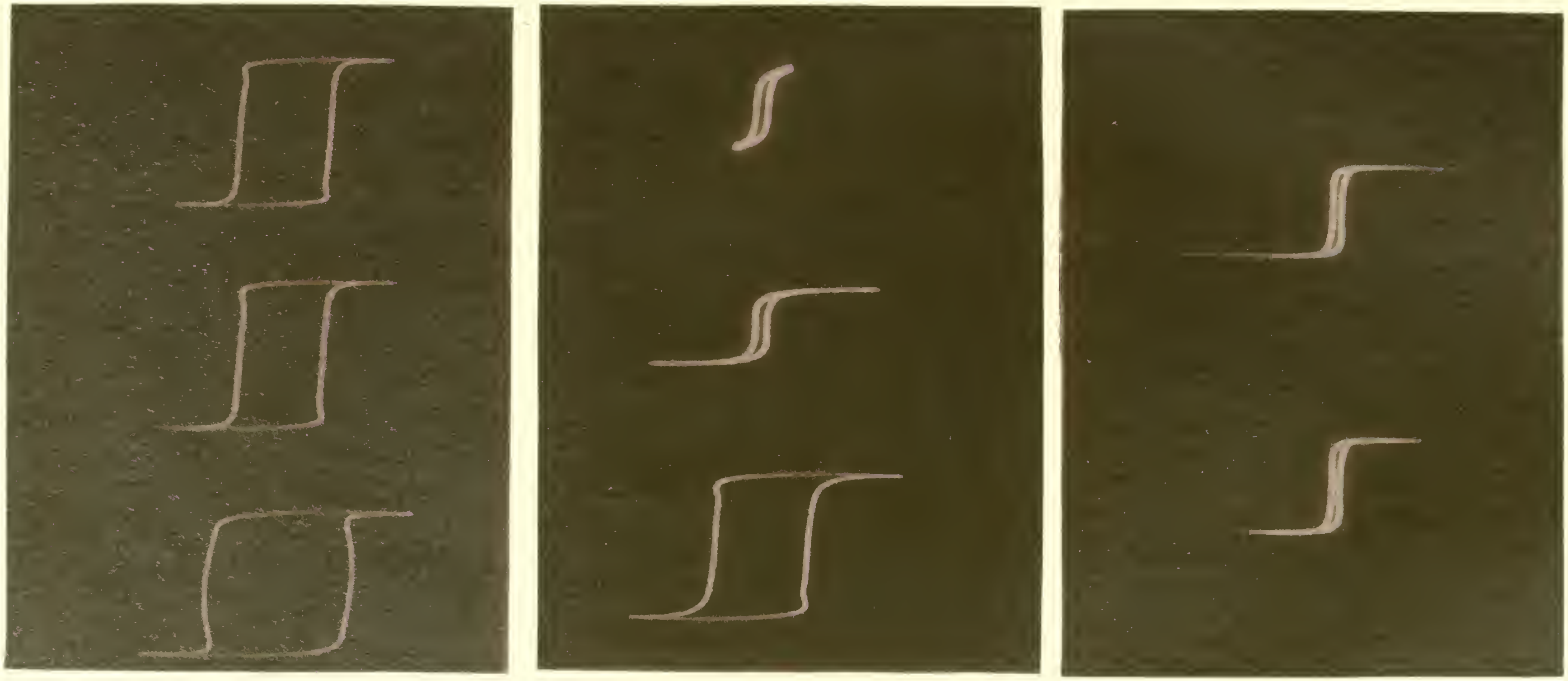




EQUIVALENT PLATE
CHARACTERISTIC OF
PERMALLOY
FIG. 10
900
800
700
600
500
400
300
200
100
0
$N_L I_L$
$N_c I_c$
600
500
400
300
200
100
.01
0
.02
.03
.04
.05
$E_a (2N_L)^{-1}$, AVG. VOLTS / TURN

RELATIVE HYSTERESIS LOOPS - FIG. 11

DELTAMAX : 27 V   PERMALLOY : 16 V   SUPERMALLOY 16 V



UPPER : DI-2	PI-1	SI-1
CENTER : DI-1	PI-2	
LOWER : DI-3	DI-4	SI-2

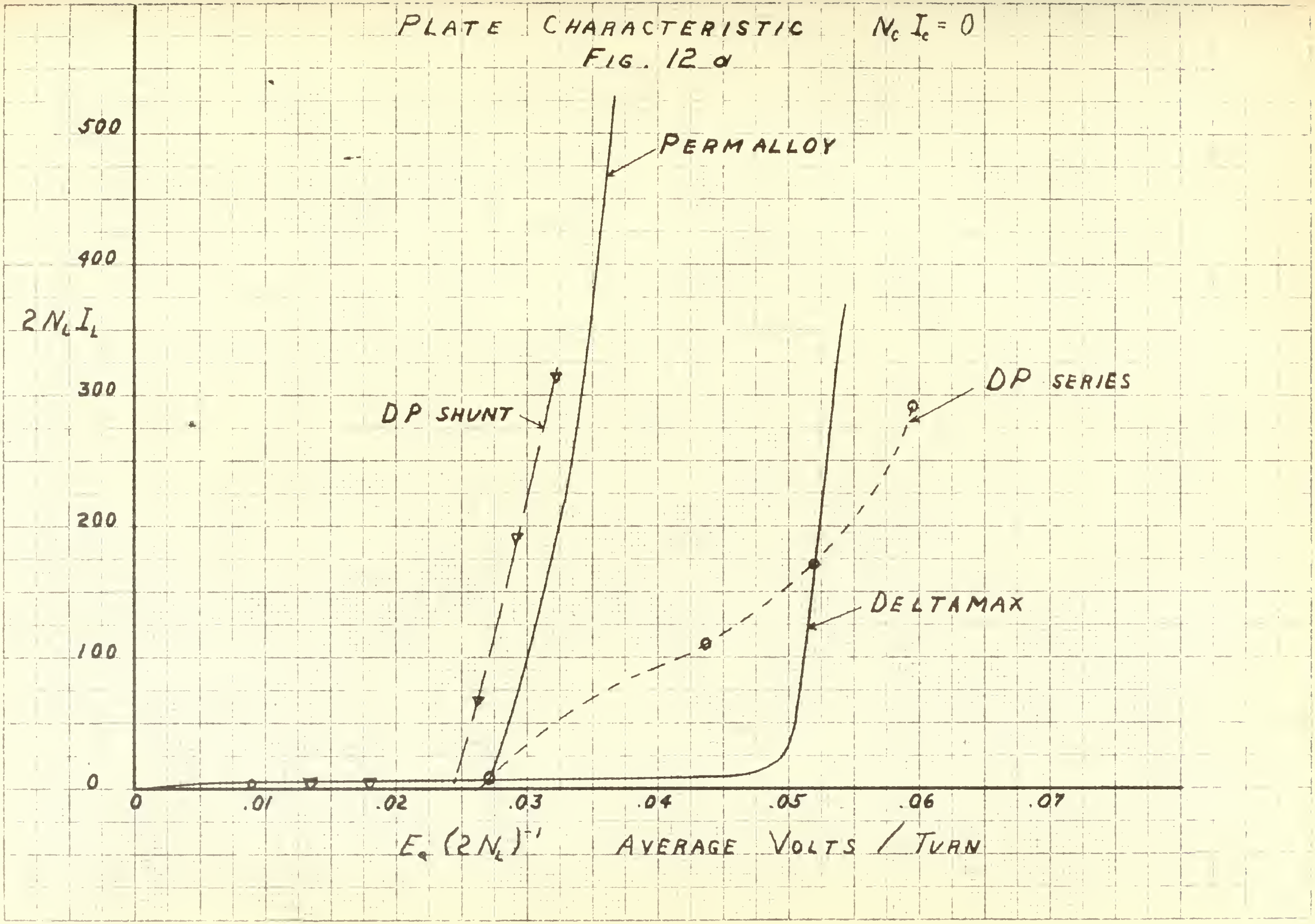


PLATE CHARACTERISTIC $N_c I_c = 0$
FIG. 12 a
PERMALLOY
DP SHUNT
DP SERIES
DELTAMAX
500
400
300
200
100
0
$2 N_L I_L$
0
.01
.02
.03
.04
.05
.06
.07
$E_a (2N_L)^{-1}$ AVERAGE VOLTS / TURN

Plate Characteristic, $N_c I_c = 0$

Fig. 12 b

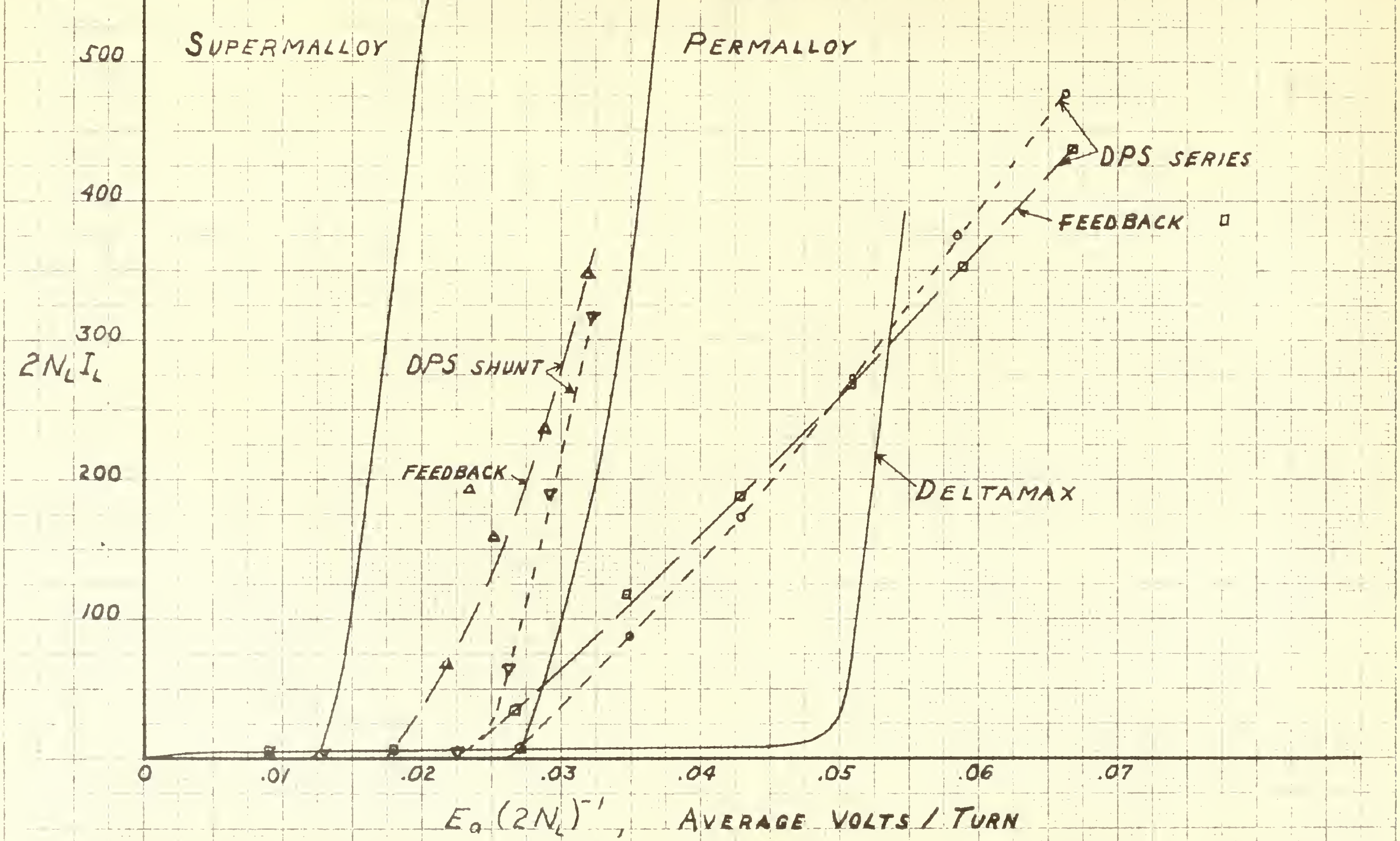
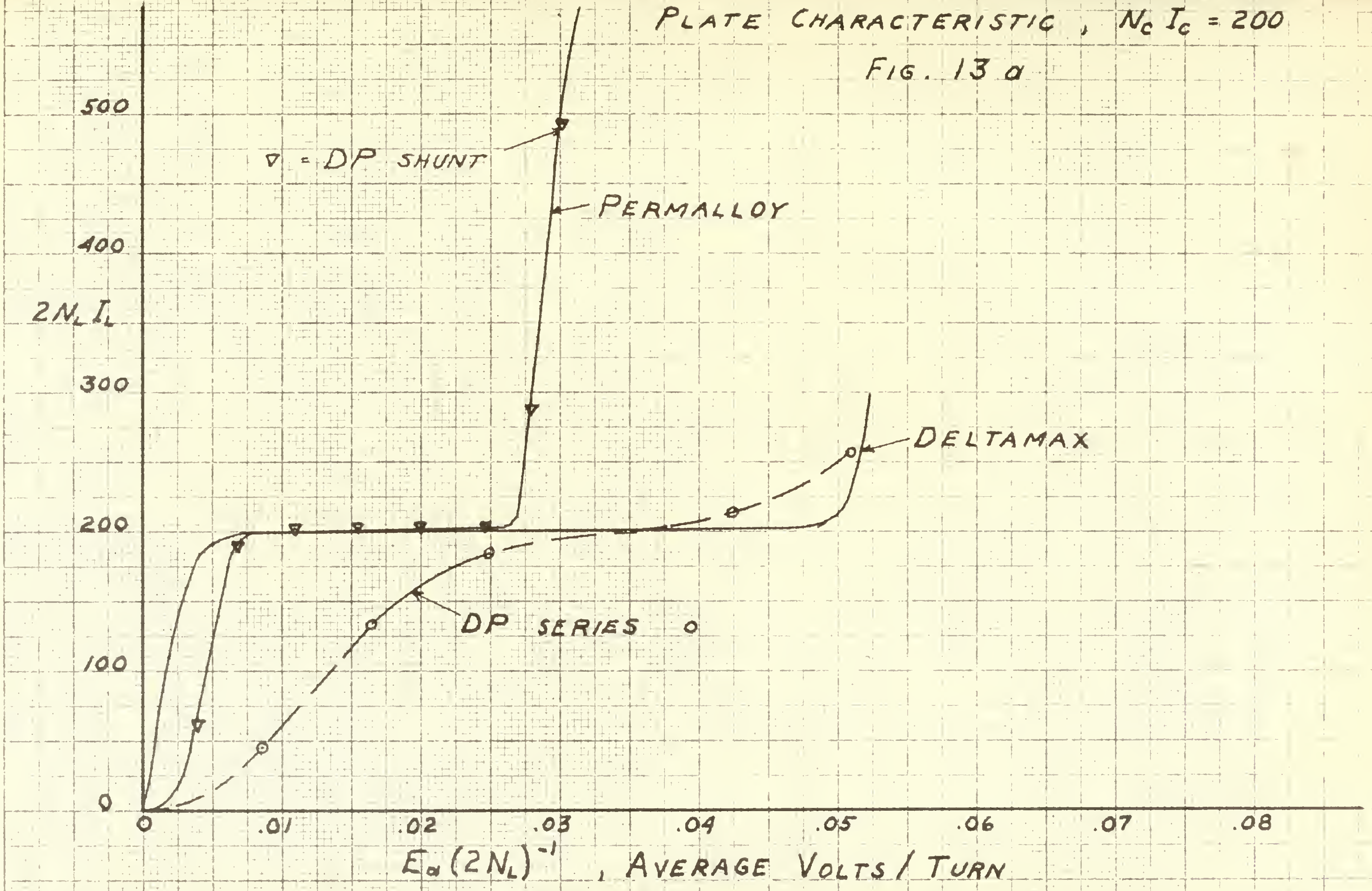


Plate Characteristic, $N_c I_c = 200$

Fig. 13 a



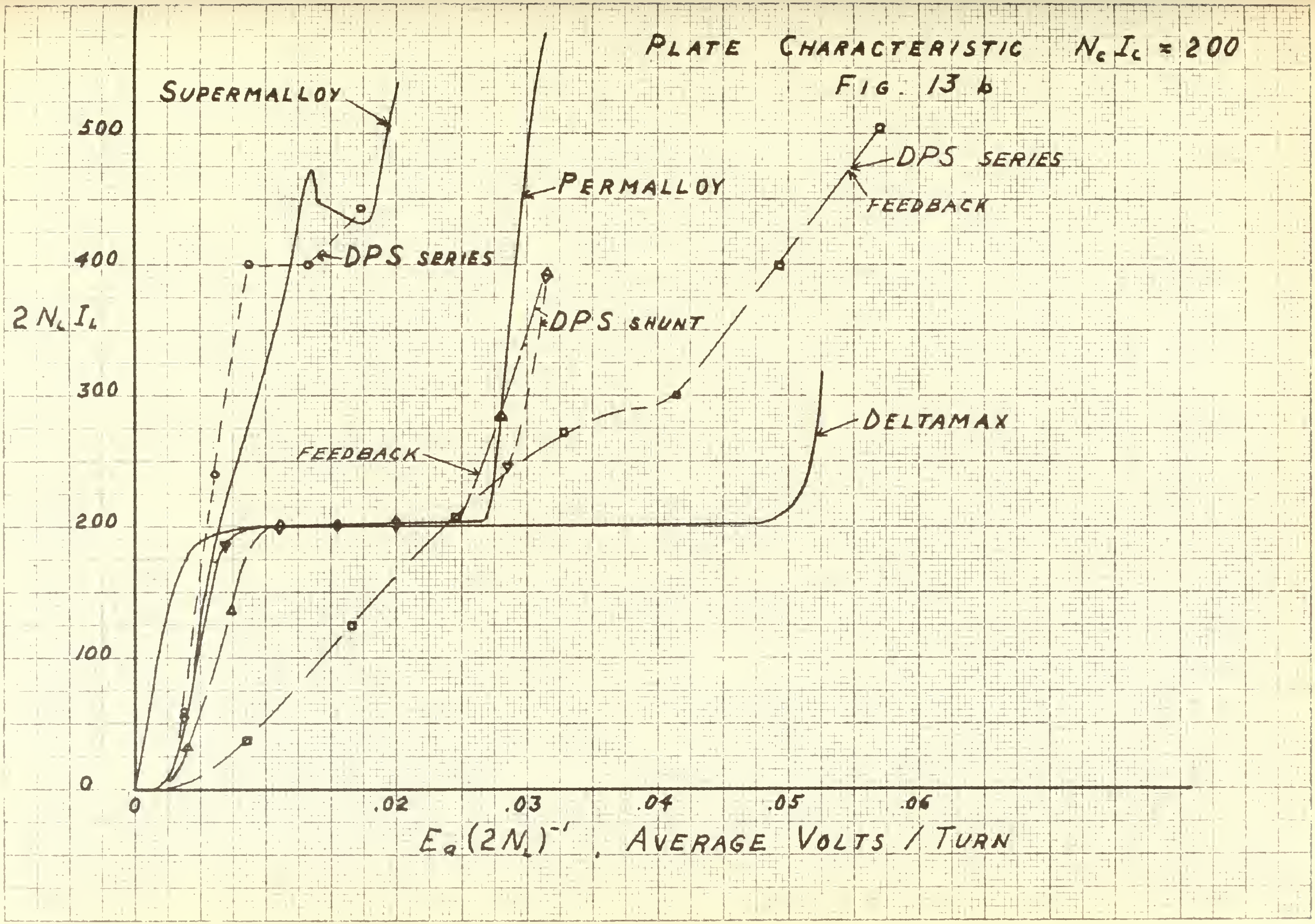
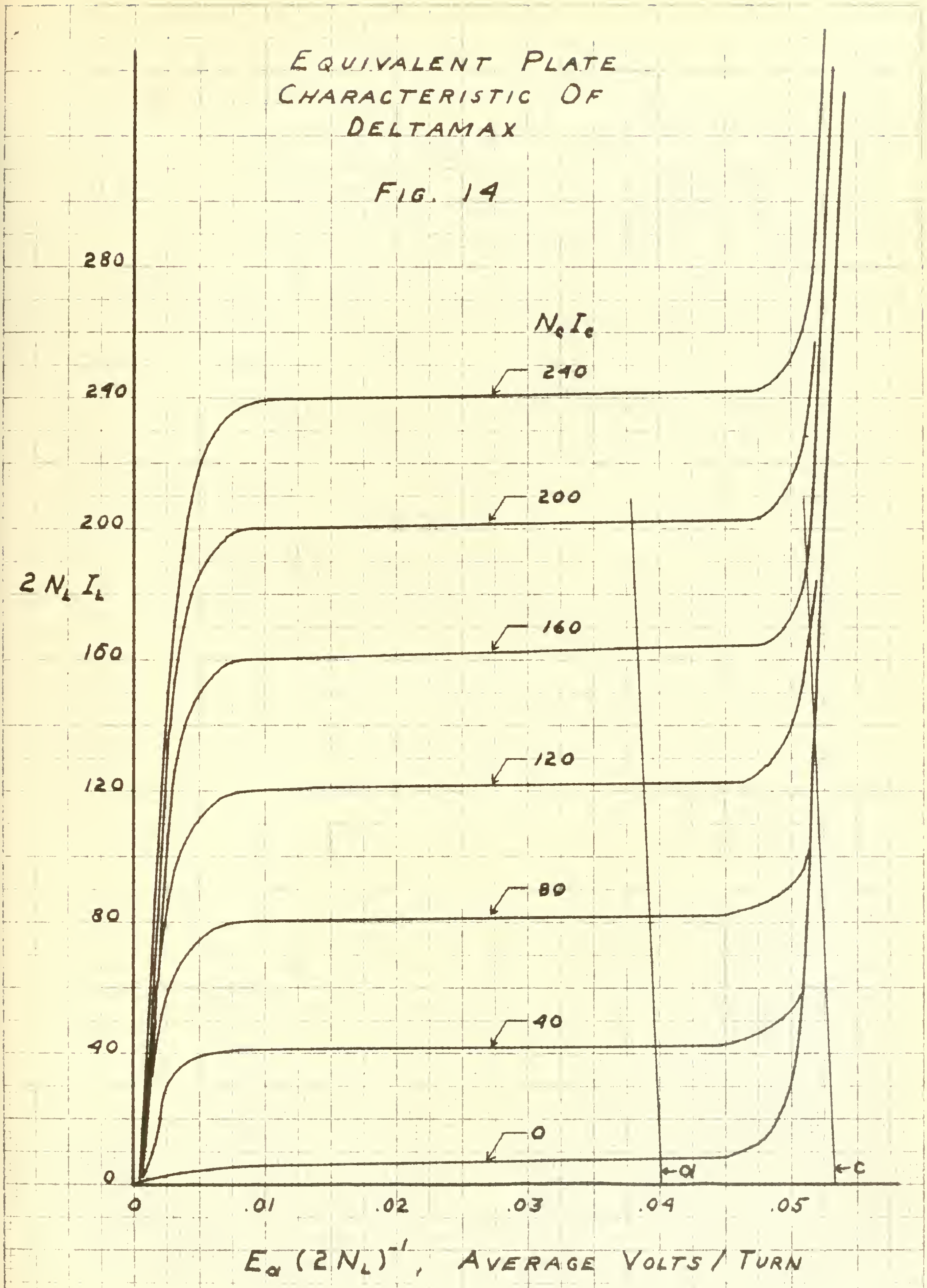


PLATE CHARACTERISTIC $N_c I_c = 200$

FIG. 13 b



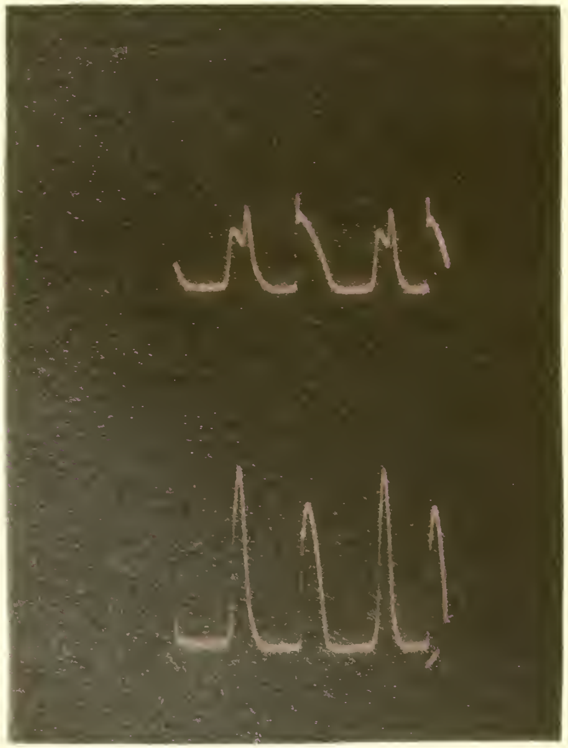
EQUIVALENT PLATE CHARACTERISTIC OF DELTAMAX

FIG. 14

VOLTAGE DROP ACROSS R_L

FIG. 15

RECTIFIED



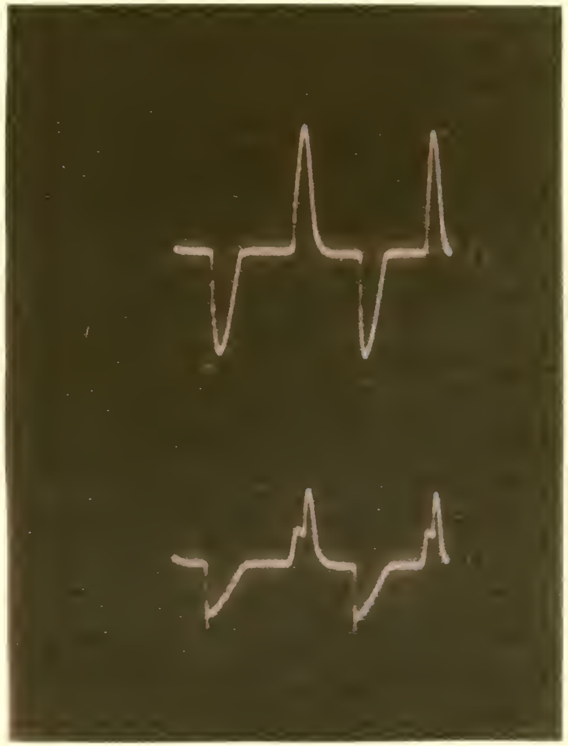
(a) UNCOMPENSATED

(b) COMPENSATED

UNRECTIFIED

(a)

(b)



(a) COMPENSATED

(b) UNCOMPENSATED

APPENDIX I

EQUATIONS

(1) $E_a - N_{L1}\phi_1' - N_{L2}\phi_2' - i_L R_L = 0$

(2) $e_{L1} = -N_{L1}\phi_1' = -L_1 i_L'$

(3) $e_{L2} = -N_{L2}\phi_2' = -L_2 i_L'$

(4) $N_1\phi_1' - N_1\phi_f' = 0$

(5) $N_2\phi_2' - N_2\phi_f' = 0$

(6) $\phi_1' = \phi_2' = \phi_f'$

(7) $E_a - 2N_L\phi_1' - i_L R_L = 0$

(8) $E_a - (2N_L - N_f)\phi_1' - i_L R_L = 0$

(9) $N_{c1}\phi_1' - N_{c2}\phi_2' + i_{ca}Z_c = 0$

(10) $N_{c1}\phi_1' = N_{c2}\phi_2'$

(11) $N_{c1}\phi_1' = N_{c2}\phi_2' = 0$

(12) $N_{c1}\phi_1' - N_{c2}\phi_2' = i_{ca}Z_c + 0$

(13) $N_{c1}\phi_1' + N_{c2}\phi_2'$

(14) $N_{c1}\phi_1' - N_{c2}\phi_2' = 0$

(15) $\phi_1' = \phi_2'$

(16) $N_1\phi_1' = i_1 r_1 + N_1\phi_f'$

(17) $$N_2 \phi'_2 = i_2 r_2 + N_2 \phi'_f$$

(18) $$N_2 \phi'_2 - N_1 \phi'_1 = (i_1 - i_2)\, r_1$$

(19) $$N_2 \phi'_2 - N_1 \phi'_1 = i_c R_c' + q/c$$

(20) $$i_c = (k/R_c)(e^{-t/R_c C})$$

(21) $$i'_c = -(k/R_c^2 C)(e^{-t/R_c C})$$

(22) $$2N_L I_L = 2N_c I_c + N_f I_L$$

(25) $$(2N_L - N_f)\, I_L = 2N_c I_c$$

APPENDIX II

NUMERICAL DATA [illegible] series

[illegible] $= [illegible]$ [illegible] $= [illegible] = 1,[illegible]$ Core 1 = [illegible]

R_L = [illegible]   [illegible] $= [illegible]$ Core [illegible] = [illegible]1-2

C = Series N_f = 10 [illegible]   Core [illegible] = [illegible]

E_{aRMS}	[illegible]	10	20	[illegible]	40	[illegible]	[illegible]	70	80
E_{aAVG}	[illegible]	[illegible]	18	[illegible]	36	45	[illegible]	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	[illegible]	[illegible]	[illegible]	7.7	[illegible]	112.0	173.0	294.0	441.0
5	[illegible]	5.2	5.7	6.9	10.8	[illegible]	173.[illegible]	296.0	[illegible]
[illegible]	[illegible]	[illegible]	9.8	11.0	13.9	65.0	175.0	297.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	67.0	177.0	[illegible]	447.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	448.0
[illegible]	[illegible]	20.6	[illegible]	[illegible]	[illegible]	69.0	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37.8	71.0	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44.4	72.0	[illegible]	[illegible]	450.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	300.0	[illegible]
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	301.0	452.0
50	[illegible]	31.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	453.0
[illegible]	0	31.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	0	32.4	[illegible]	[illegible]	72.5	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	33.3	[illegible]	64.0	[illegible]	93.0	[illegible]	304.0	455.0
70	[illegible]	34.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	305.0	455.0
75	0	35.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	456.0
80	0	[illegible]	76.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	456.0

APPENDIX II

NUMERICAL DATA [illegible] series (cont)

E_a = 400 cps $2N_1$ = [illegible] = [illegible],000   Core 1 = [illegible]

R_L = [illegible] N_1 = N_2 = NONE   Core 2 = P1-[illegible]

C = Series N_f = NONE   Core f = NONE

$E_{a\,RMS}$	0	[illegible]	20	30	40	[illegible]	60	[illegible]	[illegible]
$E_{a\,AVG}$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
90	0	35.7	[illegible]	[illegible]	[illegible]	124.0	[illegible]	[illegible]	457.0
100	0	[illegible]	[illegible]	[illegible]	110.0	134.0	186.0	[illegible]	[illegible]
110	0	[illegible]	101.0	[illegible]	119.0	144.0	[illegible]	311.0	458.0
120	0	38.3	107.5	118.0	127.0	154.0	[illegible]	312.0	459.0
130	0	39.7	114.0	[illegible]	134.0	[illegible]	192.0	313.0	460.0
140	0	39.7	120.0	[illegible]	142.0	[illegible]	199.0	314.0	[illegible]
150	0	39.8	124.0	146.0	149.0	176.0	207.0	315.0	461.0
200	0	41.1	132.5	184.0	198.0	213.0	[illegible]	322.0	472.0
250	0	41.0	137.0	199.0	245.0	250.0	292.0	338.0	478.0
300	0	41.0	137.5	210.0	291.0	293.0	328.0	[illegible]	478.0
350	0	41.0	137.5	[illegible]	324.0	346.0	357.0	414.0	487.0
400	0	41.0	137.5	211.0	342.0	387.0	397.0	[illegible]	517.0
450	0	41.0	137.5	216.0	350.0	420.0	442.0	472.0	550.0
500	0	41.0	138.0	[illegible]	355.0	443.0	487.0	[illegible]	[illegible]

APPENDIX II

[illegible] shunt

E_a = 400 cps	$2N_1 = 2N_c$ = 2,000	Core 1 = [illegible]
R_L = 18 ohms	$N_1 = N_2$ = NONE	Core 2 = P1-2
C = Shunt	N_p = NONE	Core f = NONE

E_{aRMS}	0	10	20	30	40	50	60	70	80
E_{aAVG}	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	0.6	0.9	1.1	1.4	2.2	34.0	96.0	157.0
20	0	13.0	20.0	20.0	20.0	20.0	72.0	131.0	253.0
40	0	24.0	39.0	40.0	40.0	45.0	52.0	180.0	[illegible]
60	0	24.0	60.0	60.0	60.0	60.0	61.0	175.0	265.0
80	0	27.0	79.0	80.0	80.0	80.0	80.0	159.0	258.0
100	0	29.0	94.0	100.0	100.0	101.0	100.0	143.0	245.0
120	0	30.0	102.0	120.0	120.0	120.0	120.0	137.0	232.0
140	0	30.0	102.0	138.0	139.0	140.0	140.0	141.0	221.0
160	0	30.0	104.0	155.0	159.0	159.0	159.0	159.0	217.0
180	0	30.0	106.0	170.0	178.0	179.0	179.0	179.0	222.0
200	0	31.0	110.0	[illegible]	197.0	198.0	198.0	199.0	222.0
220	0	31.0	111.0	195.0	215.0	216.0	219.0	219.0	223.0
240	0	31.0	113.0	[illegible]	232.0	238.0	238.0	238.0	239.0
260	0	31.0	114.0	191.0	247.0	257.0	259.0	259.0	259.0
280	0		[illegible]	196.0	256.0	276.0	279.0	279.0	280.0
300	0	31.0	116.0	200.0	262.0	294.0	[illegible]	[illegible]	300.0

APPENDIX II

NUMERICAL DATA OF shunt (cont)

E_g = 400 cps $\qquad$ $2N_L = 2N_c$ = 2,000 $\qquad$ Core 1 = D1-2

R_L = 48 ohms $\qquad$ $I_1 = I_2$ = NONE $\qquad$ Core 2 = P1-2

C = Shunt $\qquad$ N_f = NONE $\qquad$ Core f = NONE

E_g RMS	0	10	20	30	40	50	60	70	80
E_g AVG	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
320	0		116.0	202.0	267.0	309.0	318.0	320.0	319.0
340	0		116.0	206.0	272.0	320.0	336.0	338.0	339.0
360	0		116.0	210.0	277.0	330.0	354.0	357.0	357.0
380	0		117.0	210.0	283.0	339.0	370.0	376.0	377.0
400	0	31.0	117.0	210.0	288.0	346.0	383.0	395.0	397.0
420	0		117.0	212.0	291.0	352.0	395.0	412.0	416.0
440	0		117.0	212.0	294.0	359.0	406.0	430.0	435.0
460	0		117.0	212.0	296.0	365.0	415.0	445.0	453.0
480	0		117.0	212.0	298.0	370.0	422.0	459.0	471.0
500	0	31.0	117.0	212.0	300.0	375.0	429.0	472.0	439.0

APPENDIX II

NUMERICAL DATA CFS Series

E_s = 400 cps	$N_L = 2N_c$ = 1,000	Core 1 = [illegible]1-2
R_L = 40 ohms	$N_1 = N_{-}$ = NONE	Core [illegible] = F1-[illegible]
C = Series	f = NONE	Core f [illegible] 61-1

E_{sRMS}	0	10	20	30	40	50	60	70	80
E_{sAVG}	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	2.3	3.0	8.3	89.0	174.0	271.0	375.0	475.0
5	0	5.8	6.5	8.7	[illegible]	161.0	260.0	350.0	453.0
10	0	10.5	11.3	13.1	84.0	163.5	261.0	360.0	454.0
15	0	15.3	16.1	17.6	86.0	165.0	264.0	361.0	[illegible]
20	0	19.9	20.9	22.2	[illegible]	167.5	266.0	363.0	[illegible]
25	0	23.7	[illegible]	27.2	90.0	169.0	[illegible]	[illegible]	[illegible]
30	0	25.6	[illegible]	31.3	[illegible]	171.0	[illegible]	[illegible]	[illegible]
35	0	26.1	36.1	36.5	93.0	172.5	270.0	369.0	459.0
40	0	26.1	40.5	41.4	95.0	175.0	272.0	370.0	[illegible]
45	0	26.1	[illegible]	46.2	97.0	175.0	274.0	371.0	461.0
50	0	26.3	50.0	52.0	[illegible]	176.5	[illegible]	[illegible]	[illegible]
55	0	26.7	[illegible]	57.0	[illegible]	[illegible]	[illegible]	374.0	[illegible]
60	0	27.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	464.0
65	0	27.3	[illegible]	67.0	[illegible]	[illegible]	280.0	[illegible]	[illegible]
70	0	27.5	[illegible]	72.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	0	27.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX II

NUMERICAL DATA DPS Series (cont)

E_a = 400 cps	$2N_L = 2N_c$ = 1,000	Core 1 = D1-2
R_L = 40 ohms	$N_1 = N_2$ = NONE	Core 2 = F1-2
C = Series	$I_{[illegible]}$ = NONE	Core f = S1-1

E_{aRMS}	0	10	20	30	40	50	60	70	80
E_{aAVG}	[illegible]	[illegible]	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
90	0	28.3	90.0	91.0	110.0	[illegible]	286.0	333.0	471.0
100	0	[illegible]	99.0	101.0	113.0	[illegible]	[illegible]	385.0	474.0
110	0	28.8	106.0	110.0	117.0	194.0	291.5	[illegible]	476.0
120	0	28.8	113.0	121.0	123.0	[illegible]	294.0	390.0	473.0
130	0	29.0	116.0	130.0	132.0	202.5	297.0	392.0	481.0
140	0	29.1	117.0	140.0	[illegible]	205.5	[illegible]	394.0	484.0
150	0	29.1	117.5	150.0	151.0	[illegible]	301.0	397.0	486.0
200		30.0	120.0	200.0	200.0	222.0	312.0	404.0	500.0
250		30.0	120.0	233.0	250.0	248.0	[illegible]	420.0	505.0
300		30.0	120.0	240.0	300.0	[illegible]	343.0	432.0	524.0
350		30.0	121.0	242.0	343.0	347.0	[illegible]	447.0	536.0
400		30.0	122.0	245.0	[illegible]	[illegible]	[illegible]	460.0	549.0
450		30.0	122.0	245.0	362.0	440.0	443.0	476.0	560.0
500		30.0	122.0	246.0	367.0	461.0	496.0	500.0	572.0

APPENDIX II

NUMERICAL DATA FOR Shunt

E_s = 4[illegible] cps N_L = $2N_g$ = [illegible]   Core 1 = S1-2

R_L = [illegible] ohms N_1 = N_2 = [illegible]   Core 2 = F1-2

C = Shunt N_f = NONE   Core 3 = S1-[illegible]

E_{aRMS}	0	10	20	30	40	50	60	70	80
E_{aAVG}	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	[illegible]	0.6	0.9	1.2	1.5	[illegible]	32.7	95.0	158.0
20	0	18.0	20.0	20.0	20.0	20.0	46.0	123.0	192.0
40	0	25.0	40.0	40.0	40.0	40.0	40.0	126.0	197.0
60	0	25.0	60.0	60.0	60.0	60.0	61.0	123.0	197.0
80	[illegible]	27.0	77.0	[illegible]	80.0	80.0	81.0	123.0	196.0
100	[illegible]	29.0	93.0	100.0	100.0	100.0	101.0	123.0	195.0
120	[illegible]	30.0	99.0	120.0	120.0	120.0	121.0	125.0	195.0
140	0	31.0	100.0	133.0	140.0	140.0	140.0	141.0	198.0
160	0	31.0	103.0	156.0	159.0	159.0	160.0	160.0	202.0
180	[illegible]	31.0	[illegible]	171.0	178.0	179.0	179.0	180.0	204.0
200	0	31.0	110.0	[illegible]	[illegible]	198.0	199.0	[illegible]	208.0
220	[illegible]		110.0	186.0	216.0	218.0	218.0	219.0	221.0
240	0		111.0	[illegible]	[illegible]	237.0	238.0	[illegible]	240.0
260	0		113.0	191.0	251.0	258.0	[illegible]	[illegible]	259.0
280	[illegible]		114.0	192.0	264.0	278.0	278.0	279.0	280.0
300	0	31.0	114.0	193.0	272.0	297.0	[illegible]	[illegible]	299.0

APPENDIX II

NUMERICAL DATA DPS shunt (cont)

E_a = 400 cps	$2N_L = 2N_c = 2{,}000$	Core 1 = D1-2
R_L = 48 ohms	$N_1 = N_2 = 500$	Core 2 = P1-2
C = Shunt	N_f = NONE	Core f = S1-1

E_a RMS	0	10	20	30	40	50	60	70	80
E_a AVG	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
320	0		115.0	196.0	279.0	314.0	319.0	320.0	319.0
340	0		115.0	198.0	284.0	329.0	337.0	339.0	339.0
360	0			197.0	286.0	341.0	356.0	357.0	358.0
380	0			200.0	290.0	350.0	374.0	377.0	378.0
400	0	31.0	115.0	201.0	292.0	357.0	390.0	396.0	396.0
420	0			201.0	295.0	364.0	404.0	414.0	414.0
440	0			202.0	297.0	365.0	416.0	432.0	435.0
460	0			204.0	298.0	372.0	427.0	450.0	455.0
480	0			204.0	299.0	376.0	435.0	466.0	472.0
500	0	31.0	115.0	205.0	301.0	380.0	441.0	479.0	489.0

APPENDIX II

NUMERICAL DATA DDD shunt

E_a = 400 cps	$2N_1 = 2N_c$ = 2,000	Core 1 = D1-1
R_L = 48 ohms	$N_1 = N_2$ = 500	Core 2 = D1-2
C = Series	N_f = NONE	Core f = D1-3

E_{aRMS}	0	10	20	30	40	50	60	70	80
E_{aAVG}	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	2.0	3.0	4.0	4.0	5.0	5.0	5.0	5.5
20	0		21.0		22.0		[illegible]		23.0
40	0		41.0		42.0		42.0		43.0
60	0		61.0		62.0		63.0		62.0
80	[illegible]		81.0		82.0		82.0		83.0
100	0	46.0	100.0	100.0	102.0	102.0	102.0	102.0	103.0
120	0		115.0		122.0		122.0		[illegible]
140	0		128.0		[illegible]		[illegible]		142.0
160	0		137.0		160.0		161.0		162.0
180	0		142.0		180.0		181.0		181.0
200	0	46.0	145.0	197.0	200.0	200.0	201.0	200.0	201.0
220	0		147.0		219.0		[illegible]		[illegible]
240	0		148.0		239.0		[illegible]		241.0
260	0		148.0		258.0		260.0		[illegible]
280	0		149.0		273.0		280.0		[illegible]
300	0	49.0	149.0	251.0	297.0	[illegible]	[illegible]	[illegible]	301.0

APPENDIX II

[illegible]RICAL DATA DDD shunt (cont)

E_a = 400 cps — $N_1 = 2N_c$ = 2,000 — Core 1 = D1-1

R_L = 48 ohms — $N_1 = N_2$ = [illegible] — Core 2 = D1-2

C = Series — N_f = [illegible] — Core f = D1-3

E_a RMS	0	10	20	30	40	50	60	70	80
E_a AVG	0	9	18	27	36	[illegible]	54	63	72
I_c	I_1	I_1	I_1	I_1	I_1	I_1	I_1	I_1	I_1
[illegible]	0		149.0		312.[illegible]		[illegible]		321.0
340	0		149.0		[illegible]		340.0		341.0
360	0		150.0		376.0		359.0		[illegible]
380	[illegible]		151.0		[illegible]		[illegible]		379.0
400	0	[illegible]	[illegible]1.0	[illegible]	350.0	394.0	398.0	[illegible]	[illegible]
420	0		151.0		355.0		416.0		417.0
440	0		151.0		[illegible]		[illegible]		[illegible]
460	0		151.0		363.0		454.0		456.0
480	0		151.0		366.0		472.0		474.0
500	0	49.0	151.0	[illegible]	[illegible]	[illegible]	[illegible]	492.0	494.0

APPENDIX II

NUMERICAL DATA DFS-10 series

E_a = 400 cps	$2N_L = 2N_c = 2500$	Core 1 = D1-2
R_L = 48 ohms	$N_1 = N_2 = 500$	Core 2 = P1-2
C = Series	N_f = 250	Core f = S1-1

$E_{a\,RMS}$	0	10	20	30	40	50	60	70	80
$E_{a\,AVG}$	[illegible]	[illegible]	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	.4	.5	.9	1.1	1.5	3.5	54.0	106.0
5	0	5.0	5.6	5.8	6.1	6.2	6.9	49.0	98.0
10	0	9.5	11.4	11.5	11.6	12.0	12.6	46.0	87.0
15	0	11.6	16.8	16.9	17.0	17.6	18.0	44.0	78.0
20	0	14.0	22.2	22.4	22.5	23.2	23.5	44.0	78.0
25	0	14.3	27.6	28.0	28.0	28.6	29.0	47.5	80.0
30	0	14.7	32.8	33.4	33.7	34.2	34.7	50.0	83.0
35	0	15.3	37.8	38.7	39.0	39.6	39.9	53.0	89.0
40	0	16.0	42.5	44.0	44.5	44.9	45.1	56.0	90.0
45	0	16.7	47.0	49.2	49.7	51.0	51.0	59.0	94.0
50	0	17.2	52.0	56.0	56.0	56.0	57.0	62.0	98.0
55	0	17.6	56.0	61.0	61.0	61.0	62.0	66.0	101.0
60	0	17.9	60.0	67.0	67.5	67.5	68.0	70.0	104.0
65	0	18.1	63.0	72.0	72.5	[illegible]	74.0	75.0	108.0
70	0	18.3	[illegible]	77.0	77.5	78.0	[illegible]	[illegible]	110.0
75	0	18.4	[illegible]	[illegible]	83.0	[illegible]	[illegible]	[illegible]	113.0
80	0	18.6	70.0	[illegible]	89.0	90.0	[illegible]	[illegible]	118.0

APPENDIX II

NUMERICAL DATA DPS-10 series (cont)

f_s = 400 cps	$2N_L = 2N_c$ = 2500	Core 1 = D1-2
R_L = 48 ohms	$N_1 = N_2$ = 500	Core 2 = F1-2
C = Series	N_f = 250	Core f = S1-1

E_s RMS	0	10	20	30	40	50	60	70	80
E_s AVG	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
90	0	18.8	73.0	93.0	100.0	100.0	101.0	101.0	123.0
100	0	19.1	74.0	108.0	111.0	111.0	112.0	112.5	130.0
110	0	19.1	77.0	118.0	122.0	122.5	123.0	123.0	136.0
120	0	19.1	79.0	126.0	132.0	134.0	134.0	134.0	142.0
130	0	19.2	79.0	132.5	144.0	145.0	145.0	145.0	148.0
140	0	19.2	79.0	138.0	155.0	156.0	156.0	157.0	162.0
150	0	19.4	80.0	142.0	166.0	167.0	167.5	168.0	168.0
200	0	19.4	81.0	152.0	214.0	220.0	220.0	221.0	220.0
250	0	19.4	83.0	154.0	244.0	276.0	278.0	279.0	276.0
300	0	19.1	84.0	158.0	259.0	319.0	332.0	334.0	330.0
350	0	19.1	84.0	159.0	261.0	338.0	382.0	387.0	384.0
400	0	19.1	84.0	159.0	261.0	344.0	410.0	439.0	440.0
450	0	19.1	84.0	159.0	264.0	347.0	422.0	430.0	492.0
500	0	19.1	84.0	159.0	264.0	347.0	425.0	500.0	542.0

E_s = 400 [illegible] | R_L = [illegible] | Core [illegible]
R_I = [illegible] | [illegible] | Core [illegible]
C = Series | [illegible] | Core [illegible] = S1-1

E_s RMS	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E_s AVG	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
[illegible]	0		1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	5.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	0	11.4	13.3	[illegible]	[illegible]	[illegible]	97.[illegible]	[illegible]	[illegible]
15	0	[illegible]	17.8	[illegible]	[illegible]	[illegible]	92.0	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX II

EXPERIMENTAL DATA [illegible]3-12.5 Series (cont)

E_b = 400 cps $\quad$ [illegible] $\quad$ Core 1 = [illegible]

R_L = [illegible] $\quad$ [illegible] $\quad$ Core [illegible] = [illegible]

C = Series $\quad$ N_f = [illegible] $\quad$ Core [illegible] = [illegible]

E_{RMS}	0	[illegible]	20	30	40	[illegible]	60	[illegible]	[illegible]
E_{AVG}	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
90	0	27.6	[illegible]	[illegible]	104.0	[illegible]	130.0	[illegible]	[illegible]
100	0	27.8	[illegible]	114.0	[illegible]	116.0	136.0	159.0	[illegible]
110	0	28.1	[illegible]	[illegible]	[illegible]	127.0	141.0	[illegible]	[illegible]
120	0	[illegible]	101.0	136.0	[illegible]	148.0	147.0	[illegible]	[illegible]
130	0	[illegible]	104.0	147.0	149.0	[illegible]	[illegible]	[illegible]	[illegible]
140	0	30.2	106.0	[illegible]	160.0	[illegible]	165.0	[illegible]	[illegible]
150	0	30.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	30.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	30.3	[illegible]	195.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
300	0	30.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
400	0	[illegible]	111.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	30.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX II

NUMERICAL DATA [illegible] series

E_a = [illegible] cps	$2N_L = 2N_c = 1{,}000$	Core 1 = D1-2
R_L = 48 ohms	$N_1 = N_2 =$ 50[illegible]	Core 2 = F1-2
C = Series	N_f = 250	Core f = S1-1

$E_{a\,RMS}$	0	10	20	30	40	50	60	70	80
$E_{a\,AVG}$	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0		4.4	6.6	[illegible]	[illegible]	[illegible]	364.0	474.0	582.0
5	0	8.9	10.5	[illegible]	157.0	250.0	353.0	[illegible]	570.0
10	0	15.3	16.9	50.0	157.0	249.0	[illegible]	453.0	564.0
15	0	21.8	[illegible]	[illegible]	157.0	[illegible]	350.0	453.0	557.0
20	0	27.9	30.0	[illegible]	[illegible]	246.0	351.0	[illegible]	557.0
25	0	30.5	[illegible]	[illegible]	159.0	249.0	352.0	[illegible]	558.0
30	0	32.2	[illegible]	[illegible]	[illegible]	[illegible]	354.0	456.0	559.0
35	0	[illegible]	[illegible]	57.0	161.0	[illegible]	[illegible]	[illegible]	560.0
40	0	[illegible]	57.0	61.0	163.0	[illegible]	357.0	459.0	560.0
45	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	459.0	[illegible]
50	0	[illegible]	[illegible]	[illegible]	166.0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	35.0	[illegible]	[illegible]	167.0	[illegible]	[illegible]	462.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	171.0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
80	0	[illegible]	110.0	[illegible]	174.0	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX II

NUMERICAL DATA DPS-25 series (cont)

E_s = 400 cps $2N_L = 2N_c$ = 1,000 Core 1 = D1-2

R_L = 48 ohms $N_1 = N_2$ = 500 Core 2 = P1-2

C = Series N_f = 250 Core f = D1-1

$E_{s\,RMS}$	0	10	20	30	40	50	60	70	80
$E_{s\,AVG}$	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
90	0	35.7	122.0	125.0	176.0	269.0	370.0	472.0	574.0
100	0	35.3	125.0	138.0	177.0	271.0	373.0	475.0	577.0
110	0	35.2	125.1	151.0	181.0	274.0	376.0	479.0	578.0
120	0	35.3	125.0	164.0	184.0	277.0	378.0	482.0	582.0
130	0	35.2	125.0	177.0	187.0	280.0	380.0	486.0	584.0
140	0	35.4	128.0	190.0	194.0	284.0	384.0	488.0	588.0
150	0	37.5	129.0	201.0	205.0	288.0	389.0	490.0	590.0
200	0	37.5	125.0	209.0	271.0	300.0	400.0	504.0	604.0
250	0	38.0	127.0	212.0	334.0	342.0	410.0	518.0	616.0
300	0	37.7	125.0	212.0	344.0	408.0	423.0	530.0	628.0
350	0	37.9	125.0	213.0	342.0	450.0	474.0	541.0	638.0
400	0	37.7	125.0	214.0	347.0	457.0	543.0	553.0	648.0
450	0	37.7	125.0	214.0	347.0	459.0	572.0	608.0	660.0
500	0	37.7	[illegible]	214.0	347.0	460.0	578.0	673.0	680.0

APPENDIX II

NUMERICAL DATA DFS-25 shunt

E_a = 400cps	$2N_L = 2N_c$ = 2,000	Core 1 = D1-2
R_L = 48 ohms	$N_1 = N_2$ = 500	Core 2 = P1-2
C = Series	N_f = 500	Core f = D1-1

E_{aRMS}	0	10	20	30	40	50	60	70	80
E_{aAVG}	0	9	18	27	36	45	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	1.4	2.5	3.0	4.5	46.1	107.0	165.0	232.0
20	0	21.0	28.0	28.0	[illegible]	57.0	124.0	186.0	257.0
40	0		55.0	55.0	[illegible]	[illegible]	[illegible]	189.0	261.0
60	0		80.0	81.0	82.0	82.0	127.0	139.0	262.0
80	0		90.0	108.0	109.0		127.0	139.0	262.0
100	0	22.0	91.0	133.0	135.0		137.0	190.0	262.0
120	0		92.0	153.0	162.0	162.0	162.0	192.0	262.0
140	0		94.0	161.0	187.0		[illegible]	195.0	[illegible]
160	0		96.0	162.0	[illegible]		213.0	213.0	270.0
180	0		96.0	163.0	228.0		240.0		272.0
200	0	22.0	96.0	164.0	235.0	[illegible]	[illegible]		[illegible]
220	0		97.0		238.0	289.0	293.0		295.0
240	0		98.0		239.0	306.0	319.0	[illegible]	[illegible]
260	0		98.0		241.0	313.0	[illegible]	316.0	346.0
280	0		98.0		242.0	318.0	363.0	[illegible]	372.0
300	0	22.0	[illegible]	[illegible]	[illegible]	321.0	[illegible]	[illegible]	398.0

APPENDIX II

NUMERICAL DATA OF [illegible] (cont)

E_s = 400 cps	$2N_L = N_c$ = 2,000	Core 1 = 51-2
R_L = 48 ohms	$N_1 = N_2$ = 500	Core 2 = 11-2
C = Series	N_f = 50	Core f = 51-1

E_a RMS	0	10	20	30	40	50	60	70	80
E_a AVG	0	9	[illegible]	27	36	[illegible]	54	63	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
320	0		98.0		245.0	[illegible]	384.0	418.0	423.0
340	0		[illegible]		246.0	354.0	389.0	432.0	447.0
360	0		[illegible]		246.0		392.0	441.0	470.0
380	0		97.0		[illegible]		394.0	447.0	490.0
400	0	[illegible]	97.0	[illegible]	248.0	[illegible]	396.0	451.0	505.0
420	0		97.0		[illegible]		[illegible]	455.0	513.0
440	0		97.0		[illegible]		400.0	[illegible]	520.0
460	0		97.0		[illegible]		[illegible]	[illegible]	524.0
480	0		97.0		[illegible]		[illegible]	461.0	528.0
500	0	[illegible]	97.0	[illegible]	[illegible]	[illegible]	403.0	[illegible]	530.0

APPENDIX II

NUMERICAL DATA D[illegible]-25 [illegible]

E_a = 400 cps $\quad$ $2N_L = 2N_c$ = 2,000 $\quad$ Core 1 = D1-1

R_L = 48 ohms $\quad$ $N_1 = N_2$ = 500 $\quad$ Core 2 = D1-2

C = Series $\quad$ N_f = 500 $\quad$ Core f = D1-3

E_{aRMS}	[illegible]	10	20	30	40	50	60	[illegible]	80
E_{aAVG}	0	[illegible]	18	27	36	[illegible]	54	[illegible]	[illegible]
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	5.0	[illegible]	6.5	7.5	[illegible]	[illegible]	13.0	[illegible]
20	0	27.0	31.0		31.0		[illegible]		57.0
40	0		56.0		[illegible]		[illegible]		[illegible]
60	0		82.0		[illegible]		[illegible]		[illegible]
80	0		108.0		[illegible]		[illegible]		114.0
100	0	42.0	127.0	134.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
120	0		[illegible]		[illegible]		[illegible]		[illegible]
140	0		[illegible]		[illegible]		[illegible]		[illegible]
160	0		141.0		[illegible]		213.0		[illegible]
180	0		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	0		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]			[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX II

[illegible] DATA [illegible] 3-37.5 Series

E_a = 400 cps $\quad$ $2N_L = 2N_c$ = [illegible] $\quad$ Core 1 = [illegible]

R_L = 48 ohms $\quad$ $N_1 = N_2$ = 500 $\quad$ Core 2 = P1-[illegible]

C = Series $\quad$ N_f = 750 $\quad$ Core f = S1-1

$E_{a\,RMS}$	0	10	20	30	[illegible]	50	60	[illegible]	80
$E_{a\,AVG}$	0	9	18	27	36	45	54	[illegible]	[illegible]
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	2.9	3.5	5.2	[illegible]	94.0	[illegible]	224.0	232.0
5	[illegible]	[illegible]	10.2	11.7	[illegible]	92.0	154.0	[illegible]	[illegible]
10	[illegible]	[illegible]	19.1	19.4	[illegible]	90.0	149.0	209.0	260.0
15	0	[illegible]	[illegible]	27.8	35.1	[illegible]	144.0	200.0	247.0
20	[illegible]	[illegible]	35.0	35.5	[illegible]	90.0	144.0	199.0	244.0
25	[illegible]	25.0	[illegible]	43.0	44.2	92.0	147.0	[illegible]	246.0
30	[illegible]	[illegible]	52.0	52.0	[illegible]	96.0	149.0	203.0	248.0
35	0	[illegible]	59.0	[illegible]	59.0	97.0	151.0	[illegible]	[illegible]
40	[illegible]	[illegible]	67.5	[illegible]	[illegible]	[illegible]	153.0	[illegible]	[illegible]
45	[illegible]	[illegible]	73.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	78.	[illegible]	[illegible]	[illegible]	[illegible]	214.0	[illegible]
[illegible]	[illegible]	27.0	[illegible]	[illegible]	[illegible]	[illegible]	161.0	217.0	[illegible]
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	27.3	[illegible]	[illegible]	100.0	114.0	165.0	222.0	[illegible]
70	[illegible]	[illegible]	[illegible]	[illegible]	114.0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	26.5	[illegible]	[illegible]	122.0	[illegible]	[illegible]	[illegible]	[illegible]
80	[illegible]	26.4	[illegible]	[illegible]	[illegible]	133.0	[illegible]	230.0	[illegible]

APPENDIX II

NUMERICAL DATA DFS-37.5 series [illegible]

E_a = 40 cps — [illegible] — Core 1 = [illegible]

R_L = 4[illegible] ohms — [illegible] — Core 2 = [illegible]

C = Series — [illegible] — Core 3 = S1-1

E_{aRMS}	0	10	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E_{aAVG}	0	[illegible]	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
90	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	177.[illegible]	[illegible]	[illegible]
100	[illegible]	26.3	89.0	[illegible]	[illegible]	164.0	[illegible]	[illegible]	[illegible]
110	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
120	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
130	[illegible]	[illegible]	[illegible]	151.[illegible]	[illegible]	[illegible]	212.0	[illegible]	[illegible]
140	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
200	0	[illegible]	[illegible]	155.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
250	0	[illegible]	[illegible]	[illegible]	[illegible]	315.0	377.0	[illegible]	[illegible]
300	[illegible]	26.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX II

[illegible] series

E_g = 400 cps [illegible] = 2,000 Core [illegible]

R_L = 48 ohms [illegible] Core [illegible]

C = Series N_f = 1,000 Core [illegible]

E_{aRMS}	0	10	20	30	40	[illegible]	[illegible]	[illegible]	[illegible]
E_{aAVG}	0	[illegible]	18	27	36	45	54	[illegible]	72
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	[illegible]	5.1	7.1	52.0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	11.5	11.9	14.1	[illegible]	103.0	163.0	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	52.5	107.5	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	107.0	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	0	[illegible]	[illegible]	[illegible]	66.0	111.0	[illegible]	[illegible]	[illegible]
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	172.0	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	127.0	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX [illegible]

NUMERICAL DATA [illegible]

E_a = [illegible] N_1 = [illegible] Core 1 = [illegible]

R_L = [illegible] $N_1 = N_2$ = 300 Core 2 = [illegible]

[illegible] = Series [illegible] N_f = 1,[illegible] Core f = [illegible]

. . . .

$E_{a\,RMS}$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	60	[illegible]	80
$E_{...}$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I_c	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L	I_L
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	181.0	[illegible]	213.0	[illegible]
100	0	19.2	[illegible]	120.0	184.0	[illegible]	[illegible]	[illegible]	270.0
110	0	19.3	70.0	120.0	[illegible]	210.0	[illegible]	[illegible]	[illegible]
120	0	[illegible]	70.0	[illegible]	[illegible]	233.0	[illegible]	[illegible]	[illegible]
130	0	19.3	[illegible]	121.0	194.0	[illegible]	[illegible]	[illegible]	[illegible]
140	0	19.3	69.0	122.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150	0	19.4	[illegible]	[illegible]	[illegible]	260.0	[illegible]	304.0	307.0
200	0	19.4	68.0	[illegible]	197.0	[illegible]	[illegible]	353.0	378.0
250		19.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	420.0
300	0	19.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	425.0
350	0	19.3	[illegible]	[illegible]	[illegible]	[illegible]	325.0	[illegible]	[illegible]
400	0	19.3	[illegible]	122.0	[illegible]	[illegible]	[illegible]	[illegible]	425.0
450	0	19.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
500	0	19.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX II

PLATE CHARACTERISTICS OF PERMALLOY

E_a = 400 $2N_c = 2N_L$ = 2,000 C = shunt

Core 1 = P1-1 Core 2 = P1-2 Core f = NONE

I_c		0	50	100	150	200	[illegible]	300
$E_{a\,RMS}$	$E_{a\,AVG}$	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	0	0	0	0	0	0	0
6	5.4		5.7	7.1	7.1	7.4	8.2	10.2
8	7.2		18.1	22.7	22.4	22.4	22.4	23.7
10	9.0		35.3	43.2	42.3	44.6	47.0	60.0
12	10.8		47.5	53.0	71.0	76.0	75.0	90.0
14	12.6		48.5	[illegible]	91.0	101.0	105.0	119.0
16	14.4		49.0	97.5	106.0	128.0	134.0	152.0
18	16.2			99.0	129.0	144.0	164.0	182.0
20	18.0			100.0	143.0	168.0	185.0	209.0
22	19.8				147.0	184.0	223.0	230.0
24	21.6				147.5	192.5	236.0	252.0
26	23.4					[illegible]	[illegible]	[illegible]
[illegible]	[illegible]					[illegible]	[illegible]	[illegible]
30	27.0					[illegible]	[illegible]	[illegible]
32	28.8							[illegible]
34	30.6							[illegible]
[illegible]	[illegible]	[illegible]	[illegible]					
[illegible]	[illegible]		[illegible]					
[illegible]	49.5	[illegible]						
[illegible]	[illegible]		[illegible]					

APPENDIX II

PLATE CHARACTERISTICS OF [illegible] (cont)

E_e = 400 $\qquad$ $2T_c = 2T_L$ = [illegible] $\qquad$ C = shunt

Core 1 = P1-[illegible] $\qquad$ Core 2 = P1-[illegible] $\qquad$ Core f = [illegible]

I_c		0	50	100	150	200	250	300
E_{eRMS}	E_{eAVG}	I_L	I_L	I_L	I_L	I_L	I_L	I_L
58	52.2		68.0	101.0	150.[illegible]			
59	53.1		66.0					
60	54.0	[illegible]	[illegible]	104.0	150.0			
61	54.9		[illegible]					
[illegible]	55.5	16.[illegible]	[illegible]	14[illegible]	[illegible]	[illegible]		
[illegible]	56.[illegible]		[illegible]					
64	57.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	250.0	
66	[illegible].4	[illegible]	[illegible]	[illegible]7.0	[illegible]	[illegible]	273.0	300.[illegible]
68	61.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	275.0	301.[illegible]
70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]42.0	[illegible]	300.0	315.0
72	64.9	10[illegible]				[illegible]	320.0	[illegible]
74	66.[illegible]	[illegible]				[illegible]	347.0	[illegible]
7[illegible]	6[illegible].5		[illegible]	310.0	30[illegible]			
76	[illegible].4	1[illegible]				376.0	390.0	330.0
78	70.2	1[illegible]7.0				410.0	410.0	4[illegible].0
79	71.1		352.0					
80	72.0	217.0	351.0	392.0	3[illegible].0	44[illegible].0	[illegible]	44[illegible].0
81	72.9		31[illegible].0					
82	73.8	27[illegible].0	322.0					490.0
83	74.7						496.0	

APPENDIX II

PLATE CHARACTERISTICS OF [illegible] (cont)

E_a = 400 [illegible] = [illegible] = [illegible],000 [illegible] = short

Core 1 = [illegible]-1 Core 2 [illegible] [illegible]-2 Core [illegible] = NONE

I_c		0	[illegible]	[illegible]	150	[illegible]	[illegible]	300
E_{GRMS}	E_{GAV}	I_1	I_1	I_1	I_1	I_1	I_1	I_1
[illegible]4	[illegible]	310.0	351.0			[illegible]		
[illegible]	[illegible]			[illegible]4.0	458.0			
[illegible]	7[illegible]	3[illegible]5.0	[illegible]					
[illegible]	79.2	377.0	420.0					
[illegible]	81.0	40[illegible].0	[illegible]					

APPENDIX II

PLATE CHARACTERISTICS OF DELTAMAX

E_a = 400cps $2N_c = 2N_L$ = [illegible] [illegible] = shunt

Core 1 = S1-3 Core 2 = S1-4 Core [illegible] = NONE

I_c	[illegible]	0	[illegible]	40	60	80	100	120
E_aRMS	E_aAVG	I_L	I_L	I_L	I_L	I_L	I_L	I_L
0	0	0	0	0	0	0	0	0
5	4.5	1.[illegible]	13.6	26.5	38.0	[illegible]0.5	61.0	70.0
10	9.0	1.9	19.0	37.0	[illegible]5.5	74.0	[illegible]1.0	107.0
15	13.5	2.3	20.0	39.5	59.0	79.0	99.0	117.0
20	18.0	2.7	20.5	40.0	60.0	[illegible]0.0	100.0	11[illegible].5
25	22.5	[illegible].9	20.5	40.0	60.5	[illegible]	10[illegible]	11[illegible].5
30	27.0	3.[illegible]	20.5	40.[illegible]	60.5	[illegible]0.5	100.[illegible]	120.0
40	36.0	3.6	21.0	41.0	6[illegible].0	[illegible].5	101.0	120.0
50	44.9	3.[illegible]	21.0	41.0	61.0	[illegible]1.0	1[illegible].0	120.[illegible]
60	53.9	4.[illegible]	21.5	41.[illegible]	61.0	81.0	101.[illegible]	120.5
70	62.9	4.2	21.5	41.0	61.5	81.0	1[illegible]1.0	120.[illegible]
80	71.9	4.2	21.5	41.5	61.5	[illegible]	10[illegible].5	120.5
[illegible]	80.9	4.1	21.5	41.5	61.5	81.5	1[illegible].5	121.0
100	89.9	4.3	22.0	41.5	61.5	[illegible].5	[illegible]	[illegible]
1[illegible]5	94.4	[illegible].8	[illegible]	[illegible]	[illegible]	[illegible]	10[illegible].5	121.0
110	98.[illegible]	11.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
115	103.3	62.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
120	[illegible]7.8	150.[illegible]	150.0	150.0	[illegible]	[illegible]	[illegible]	[illegible]
2	1.[illegible]	.4		[illegible].1		16.[illegible]		[illegible]5.0
4	3.0	.[illegible]		[illegible]1.0		4[illegible]		[illegible].0

APPENDIX III

DESCRIPTION OF EQUIPMENT

Magnetic Cores - All cores used were toroidal tape-wound cores, 1 mil tape thickness, Arnold Engineering Co. Case No. 4179. The letter and first number of the core designation is designation used by Arnold Engineering Co. to designate core material and tape thickness in mils, respectively. The second number is an identifying number assigned to a particular core by the Electrical Engineering Dept., U. S. Naval Postgraduate School.

C - 5 microfarad electrolytic capacitor.

E_a - Obtained from variac supplied by 120 volt, 400 cycle generator through an isolation transformer. Measured with VTVM.

E_c - Obtained from slide wire potentiometer supplied by 36 volt battery.

i_c, i_L - Measured using Weston direct current milliampere meters, 0-500 range.

Hysteresis loops - Obtained using RC intergrating circuit. Actual values of B and H not obtained. Used for comparison only.

Rectifier - Selenium bridge rectifier.

R_c - 50 ohm power resistor to limit current.

R_L - 48 ohms slide wire resistor.